DEVELOPMENT AND APPLICATION OF A BEHAVIOURAL SCIENCE PARADIGM FOR INFECTION PREVENTION

Cumulative thesis

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Summary (EN)

Healthcare provider (HCP) behaviours play a critical role in preventing negative patient outcomes, such as healthcare associated infections (HAIs). Yet, HCP compliance with basic infection prevention practices to prevent transmission of infectious organisms remains low. Further, current guidelines may not consider the full range of behaviours involved in pathogen transmission. A thorough understanding of healthcare provider behaviours relevant for infection prevention, as well as the mechanisms that drive these behaviours is paramount to designing effective behaviour change interventions.

This thesis thus develops and applies a behavioural science paradigm to address these limitations and to guide infection prevention efforts. This thesis is comprised of eight studies and is presented in two parts. Part 1 employs exploratory and structured observations, video-based observations, and Delphi expert consensus to identify, classify, quantify, and assess the clinical relevance of HCP behaviours related to transmission of microorganisms that play a role in patient infection. Part 2 employs multiple behavioural analytical methods (e.g. concept-mapping, video-reflexive ethnography, and systematic literature review) to understand the range of factors that influence HCP infectious risk behaviours.

The findings of this thesis lay the framework for designing theoretically coherent interventions to support safe HCP behaviours and thereby reduce infectious patient risks.

ZUSAMMENFASSUNG (DE)

Das Verhalten von Mitarbeitenden des Gesundheitswesens spielt eine entscheidende Rolle bei der Verhinderung von spitalerworbenen Infektionen. Die Umsetzung von infektionspräventiven Massnahmen, wie z.B. der Händehygiene, bleibt jedoch weltweit weiterhin mangelhaft. Um dieses Verhalten positiv zu beeinflussen, braucht es ein differenziertes Verständnis des infektionsauslösenden Risikoverhaltens von Mitarbeitenden als auch der Determinanten dieses Verhaltens.

In zwei Teilen und acht Studien wird ein verhaltenswissenschaftliches Paradigma entworfen und angewandt, um die Mängel in der Umsetzung von präventiven Massnahmen zu identifizieren und damit der Infektionsprävention neue Ansätze zu eröffnen. Teil 1 verwendet verschiedene Methoden wie unstrukturierte und strukturierte Beobachtungen, indirekte, videobasierte Beobachtungen und eine Delphi-Expertenbefragung zur Identifizierung, Klassifizierung und Quantifizierung des genannten Risikoverhaltens. Teil 2 nutzt verhaltensanalytische Methoden wie Konzept-Mapping, Video-reflexive Ethnographie und eine systematische Literaturübersicht, um die ausschlaggebenden Determinanten für dieses Verhalten zu identifizieren.

Die Ergebnisse dieser Arbeit bilden die Grundlage für theoretisch fundierte Interventionen zur Förderung eines infektionspräventiven Verhaltens von Mitarbeitenden des Gesundheitswesens im Sinne einer erhöhten Patientensicherheit.

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1. Chapter 1: Introduction and Motivation

In this chapter, the motivational basis for this thesis is presented. It begins with a brief general discussion (1.1) of the importance healthcare provider behaviours in healthcare generally. The theoretical background section (1.2) goes into more detail about the current state of the field of infection prevention (1.2.1) and what is to be gained by the application of behavioural sciences (1.2.2). Finally, the “infectious risk moments” approach guided by a behavioural science paradigm for infection prevention is presented (1.3), and the study questions, structure, and aims of this thesis are described (1.4).

1.1. General introduction

Healthcare provider (HCP) behaviours play a critical role in both assuring optimal patient care and preventing negative outcomes. In a constant effort to improve quality of care, the field of hospital medicine is rife with studies demonstrating the effectiveness of interventions to improve patient outcomes by changing healthcare provider behaviours. However, the translation of such evidence into routine clinical practice is challenging and these efforts often fail to replicate the improvements reported in original research studies (Eccles, Grimshaw, Walker, Johnston, & Pitts, 2005).

This is especially true in the field of hospital infection prevention and control (IPC), where healthcare associated infections (HAIs) affect more than 2.5 million patients in Europe each year (Cassini et al., 2016), and roughly 11% of intensive care patients hospitalised in Switzerland (Pittet et al., 1999a). These infections are associated with attributable mortality and negatively influence clinical outcomes, length of hospital stay, and healthcare costs. Multiple systematic literature reviews and meta-analyses have demonstrated that a significant portion, up to 50%, of HAIs may be prevented through the application of evidence-based best practices, many of which involve changes in healthcare provider behaviours (Harbarth, Sax, & Gastmeier, 2003; Umscheid et al., 2011). Yet healthcare provider compliance with basic infection prevention practices, such as hand antisepsis with alcohol-based hand rub (henceforth, “hand hygiene”) and standard precautions to prevent transmission of infectious organisms, remains low (Gammon, Morgan-Samuel, & Gould, 2008; Erasmus et al., 2010; Edwards et al., 2012). The field of infection prevention could stand to benefit greatly from the application of behavioural theories to identify influences on healthcare provider behaviour, to understand the mechanisms underlying behaviour change processes, and to inform future interventions to promote patient safety (Atkins et al., 2017).

Previous efforts applying behavioural science to the field of infection prevention have focused primarily on hand hygiene and have only been informed to a limited extent by behaviour change theories (O'Boyle, Henly, & Larson, 2001; White et al., 2015). A number of studies have shown that behaviours beyond those involving hands may be implicated in the transmission of microorganisms relevant to patient colonisation and infection. These behaviours include handling of mobile objects (Clack, Schmutz, Manser, & Sax, 2014; Livshiz-Riven, Borer, Nativ, Eskira, & Larson, 2015), healthcare provider private (Lopez, Ron, Parthasarathy, Soothill, & Spitz, 2009) and professional attire (Treakle et al., 2009; Wiener-Well et al., 2011), and medical devices (Schultsz et al., 2003; Birnbach, Rosen, Fitzpatrick, Carling, & Munoz-Price, 2015; Livshiz-Riven et al., 2015). A thorough understanding of healthcare provider behaviours relevant for infection prevention, as well as the mechanisms that drive these behaviours is paramount to designing effective behaviour change interventions.

Because healthcare systems have limited resources, the question of where and how we invest in quality improvement is an important one. This thesis presents a behavioural science paradigm to complement traditional epidemiological methods and to guide infection prevention efforts. The thesis is presented in two parts, driven by two primary research questions that are grounded in the proposed behavioural science paradigm for infection prevention:

Q1.) Which healthcare provider behaviours are clinically relevant for transmission of pathogens?

The first section of this thesis presents multiple methods for observing, classifying, and quantifying healthcare provider behaviours that may be relevant for infectious risks. A method is then proposed for assessing clinical relevance and prioritising identified infectious risk moments.

Q2) What are the factors that influence healthcare provider behaviours relevant to infectious risks a) in general and b) specific to identified “infectious risk moments”?

The second section then employs multiple methods for performing behavioural analysis, that is, for understanding the behavioural determinants that influence healthcare provider behaviours relevant to infectious risks. This section includes a theoretical exploration of determinants based on published literature, as well as empirical methods to understand the factors that influence HCP behaviours.

This thesis is presented in seven chapters to prepare and answer the two study questions. Chapter 1 introduces the theoretical background and motivation for this thesis. Chapter 2 presents a pilot study demonstrating the feasibility of the overall infectious risk moment approach guided by the behavioural science paradigm. Chapters 3-4 address the first study question, composing Part 1 of the thesis. Chapter 3 is composed of two studies applying different methodologies for identifying the behaviours relevant to infectious risks. Chapter 4 is composed of one study applying a Delphi expert consensus method to assess the clinical relevance of the infectious risk moments identified. Chapters 5-6 address the second question, composing part 2 of the thesis. Chapter 5 is composed of three studies using empirical methods to understand the factors that influence healthcare provider behaviours specific to infectious risk moments. Chapter 6 reports on the published barriers and enablers of healthcare provider compliance with published infection prevention guidelines. Chapter 7 includes an overarching discussion of all studies and discusses the practical implications of this work as well as implications for future work.

1.2. Theoretical Background

In this section, the theoretical background is introduced in two parts. First, the field of hospital infection prevention is presented including a brief description of the epidemiology of healthcare associated infections and current approaches and challenges to their prevention. Second, the field of health psychology is presented and the behaviour of healthcare providers to prevent patient infections are framed as relevant health behaviours for which health psychology approaches may be beneficial.

1.2.1. Hospital Infection Prevention

1.2.1.1. Epidemiology of healthcare associated infections

Healthcare-associated infections (HAI), defined as infections that occur during the course of receiving medical treatment in a healthcare facility, are among the most frequent adverse events in healthcare delivery, making them an important threat to patient safety and a major public health concern (Jha, Prasopa-Plaizier, Larizgoitia, & Bates, 2010). Such infections affect hundreds of millions of patients each year, leading to significant attributed mortality, increased length of hospital stays, long-term disability, and significant financial costs for healthcare systems, patients and families. The World Health Organisation (WHO) estimates that for every 100 hospitalised patients, 7 in developed and 10 in developing countries will acquire at least one HAI. These numbers rise to 30% of patients hospitalised in intensive care units (ICUs) worldwide (WHO, 2011).

The causes of healthcare-associated infections are multifactorial, involving a series of complex interactions between an *agent* (i.e. the microorganisms associated with infection), the *host* that may be susceptible to the agent (i.e. patients under the care of healthcare providers), and the shared *environment* in which both the agent and the host are located (i.e. the healthcare environment) (Siegel, Rhinehard, Jackson, Chiarello, & Committee, 2007; Mayhall, 2012). These interactions may be modelled as a triangle, as shown in Figure 1.

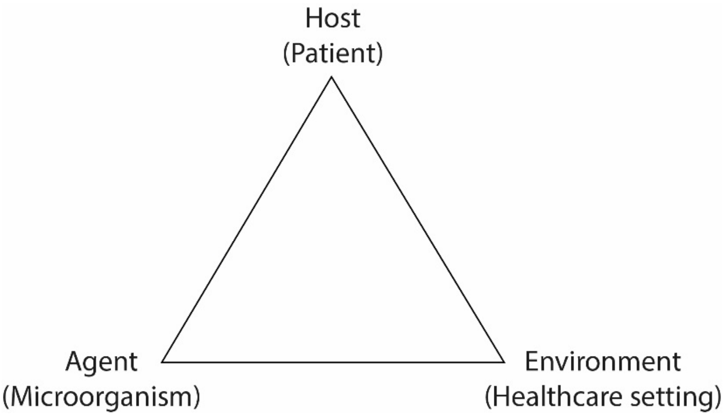

Figure 1: Triangle model of the interaction between agent, host and environment relevant to healthcare-associated infection. (Adapted from Mayhall, 2012)

The interactions that determine the probability of a microbiologic agent resulting in host infection can be represented by the following equation:

$$I_p = (D \times S \times T \times V) / H_d,$$

where I_p is the probability of infection, D is the dose (number of microorganisms) transmitted to the host, S is the receptivity of the host site coming into contact with the agent, T is the time or duration of contact (either sufficient for attachment and multiplication or not) and V is the virulence of the microorganism. The denominator (H_d) represents the host's combined defences (e.g. immune system) attempting to prevent infection (Mayhall, 2012). In addition to infection, another relevant clinical outcome is *colonisation,* defined as the presence of a growing and multiplying microorganism on or in a host, but without clinical expression or detected immune response (Mayhall, 2012).

The *transmission* of microorganisms is of particular interest, because for infection or colonisation to take place, microorganisms should be transferred (or have previously been transferred) from a reservoir to a susceptible host. Within the healthcare environment, potential reservoirs include patients themselves, healthcare providers, as well as inanimate elements of the physical environment such as tap water, furniture, medical devices, and mobile objects, where microorganisms can survive and multiply. Transmission may occur through *direct contact* (e.g. infected or colonised HCP directly transmitting to patient without contaminated intermediate object or person) or through *indirect contact transmission* via contaminated intermediate objects or persons transiently carrying microorganisms (Siegel et al., 2007). The contaminated intermediate objects or persons involved in *indirect contact transmission* may be referred to as vectors. These vectors may include care devices, mobile objects, and HCP hands, clothing, and accessories. Other means of transmission include *droplet* or *airborne* transmission via respiratory droplets or airborne droplet nuclei and small, respirable particles. Indirect contact transmission is the most common transfer mechanism in healthcare settings and the hands of healthcare providers are widely recognised as playing an important role in the transfer of infection-causing microorganisms. As such, hand hygiene using alcohol-based handrub (ABHR) is regarded as one of the most important measures to prevent HAI by reducing transmission (Allegranzi & Pittet, 2009).

1.2.1.2. Preventability of healthcare-associated infections

Over 30 years ago, the landmark Study on the Efficacy of Nosocomial Infection Control (SENIC) conducted by the Centers for Disease Control and Prevention found that 30-35% of HAIs were preventable (Haley et al., 1985). Since then, numerous studies have examined the efficacy of interventions to reduce the most prevalent HAIs, including central-line-associated bloodstream infections (CLABSI), catheter-associated urinary tract infections (CAUTI), ventilator-associated pneumonia (VAP) and surgical site infection (SSI). More recent systematic reviews and meta-analyses have established that a significant portion, up to 70%, of HAIs may be prevented through the systematic application of preventative measures (Harbarth et al., 2003; Umscheid et al., 2011; Zingg et al., 2015; Storr et al., 2017). Although one may expect the preventable proportion of infections to reduce over time as would be predicted by the law of diminishing returns, (Mold, Hamm, & McCarthy, 2010) a recent report conducted by Kuster et al. (unpublished) found the preventable proportion of infections remained in the range of 35-55%. This sustained preventable proportion may be related to a globally aging patient population with increased multi-morbidities, together with advanced techniques allowing older and sicker patients to be eligible for treatments that would earlier not have been previously possible. Nonetheless, these results suggest that there is still room for considerable improvement.

Interventions to prevent and control HAIs can be broadly distinguished into three groups. These include interventions designed to (1) minimize or eliminate reservoirs of microorganisms from the healthcare environment, (2) interrupt the transmission of infectious agents, or (3) protect the host (Figure 2). Many of the same measures are employed for both eliminating environmental reservoirs and interrupting transmission of microorganisms. These include behaviours such as environmental disinfection, hand hygiene, and use of barriers such as gloves, gowns, and eye protection (Mayhall, 2012). Several evidence-based guidelines exist, and are promoted by national and international bodies, to promote the uptake of standard (previously, “universal”) and isolation precautions to reduce the transmission of microorganisms that cause patient colonisation and infection (Department of Health, 1998; Siegel et al., 2007; Pittet, Allegranzi, & Boyce, 2009). Although demonstrated to be effective in reducing rates of HAIs, healthcare provider compliance with such measures remains internationally suboptimal (Larson & Kretzer, 1995; Weber et al., 2007; Gammon et al., 2008). While compliance is amenable to some improvement following structured interventions, current research is inconclusive about the sustained effect of such improvements (Gammon et al., 2008).

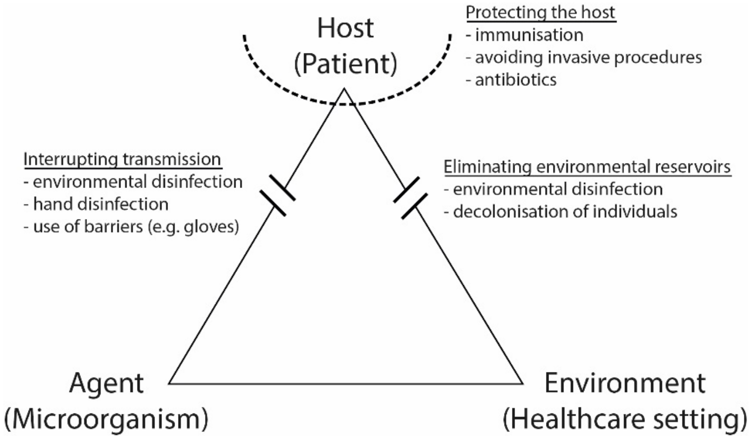

Figure 2: Means of prevention directed at breaking links in the chain of infection

1.2.2. Health psychology applied to infection prevention

1.2.2.1. Framing infection prevention measures as health behaviours

Achieving improvement in compliance with infection prevention measures often requires a change in the behaviours of individual healthcare providers (HCPs) who provide care. This represents a key challenge for the field of infection prevention, which could thus stand to benefit greatly from behavioural science insights (Pittet, 2004). The field of health psychology, specifically, is concerned with the application of psychological methods to better understand and promote health behaviours, prevent illness and improve healthcare (Matarazzo, 1980). Health behaviours of interest to health psychologists include those involved in the primary prevention of disease and promotion of healthy lifestyle (e.g. smoking cessation, reducing excessive alcohol consumption, partaking in physical activity and healthy diet). A second type of relevant health behaviours are those that limit the progression and effects of chronic conditions (e.g. medication adherence, attending medical consultation appropriately) (Sabaté, 2003). A third set of relevant health behaviours are those of the practitioners involved in the delivery of healthcare and translating evidence-based findings into clinical practice (e.g. ensuring patients receive treatments of proven effectiveness, preventing adverse events) (Michie et al., 2005; Vincent, Wearden, & French, 2015). Behaviours relevant for hospital infection prevention, such as complying with hand hygiene and employing aseptic technique, fall under this latter category (Figure 3).

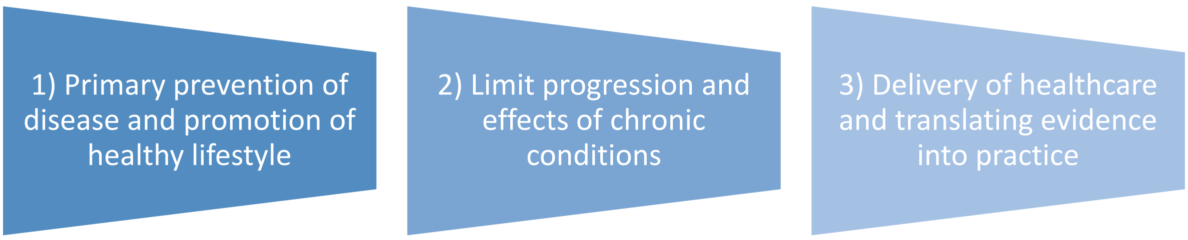

Figure 3: Types of health behaviours

It is useful to frame healthcare provider behaviours to protect patients as health behaviours within the context of health psychology, because this field offers theories and methods to understand, explain, and intervene in behavioural patterns (Schwarzer & Gutiérrez-Doña, 2000). The term "theory" can be broadly defined as a description of a system that provides an explanation for what is known and can be used to explain and predict phenomena. Specifically within the field of health behaviour change, "theories seek to explain why, when, and how a behaviour does or does not occur, and the important sources of influence to be targeted in order to alter the behaviour" (Michie, West, Campbell, Brown, & Gainforth, 2014b).

Theory plays an important role in the field of health psychology, serving for example to reduce the number of possible variables and mechanisms that need to be explored when conducting behavioural studies and offering an explanation for why certain interventions are effective by illuminating causal processes. Theories further help to advance the science of health psychology and behaviour change by offering a standardised terminology and informing methodological approaches to test theories across different contexts (Michie, Johnston, Francis, Hardeman, & Eccles, 2008).

Despite the recognized important of using behavioural theory, a 2012 systematic literature review on the effectiveness and sustainability of interventions to change HCP behaviours and improve adherence to infection prevention guidelines in acute care found that none of the 21 included intervention studies explicitly incorporated psychological theory (Edwards et al., 2012). A more recent literature review of factors influencing HCP compliance with infection prevention guidelines revealed that only 47 of 329 included studies (14%) included any reference to behavioural theory (Clack et al., (unpublished BAG report)). Of those studies referencing behavioural theory, the vast majority concerned HCP compliance with hand hygiene, and the predominant theory employed was the Theory of Planned Behaviour (TPB)

(21%, n=10) (Ajzen, 1985), where the TPB was usually used to deductively interpret study results. Even among studies citing psychological theories, it remains unclear how certain theories are selected for use, and the extent to which these are actually used (Painter, Borba, Hynes, Mays, & Glanz, 2008).

1.2.2.2. Considerations of existing health psychology theories

Another important consideration is that many existing health psychology theories were designed to address behaviours of an individual acting in the interest of promoting their own health (Vincent et al., 2015). It remains unclear if such models have the same predictive value when applied to health behaviours in the interest of another individual's health, as is the case for many infection prevention behaviours. For example, several behavioural theories include some form of "outcome expectancies" (also referred to as "beliefs about consequences") as a theoretical construct (Rosenstock, Strecher, & Becker, 1988; Schwarzer, 1992). Outcome expectancies refer to a person's beliefs about the positive or negative consequences of performing a behaviour. In theories where outcome expectancies do not explicitly figure as a central theoretical construct, they are often accounted for as relating to an individual's attitudes and behavioural beliefs (Ajzen, 1985), and contributing to one's motivation to perform a certain behaviour (Rogers, 1975; Michie, van Stralen, & West, 2011). When applied to HCP infection prevention behaviours, the consequences of a behaviour, such as not performing hand hygiene before patient contact, may be social (e.g. disapproval from colleagues), but the health consequences will most often affect the patient, rather than the individual not performing the behaviour.

Another, closely related, theoretical construct, "threat appraisal" (also "perceived threat") also appears in several behavioural theories (Rogers, 1975; Rosenstock et al., 1988; Schwarzer, 1992) as a determinant of intention to perform a behaviour. Threat appraisal refers to an individual's perception about the likelihood of contracting a disease (vulnerability) and the perceived severity of that disease (severity). Again, when applied to HCP infection prevention behaviours, the health threat posed by lack of infection prevention behaviours is that the patient may contract an infection, a delayed outcome that cannot easily be traced back to an individual HCP. It remains to be explored, whether beliefs about patient consequences or health threats to patients play the same role in motivating HCP behaviour as when the threats concern one's own health.

While the TPB appears to be the most commonly employed model used in health services research, it also has some important limitations. For example, the TPB has been found to be a better predictor of self-report behaviour (e.g. self-reported hand hygiene) than actual, observed behaviour (Armitage & Conner, 2001; McEachan, Conner, Taylor, & Lawton, 2011). Further, the TPB focuses exclusively on explicit reasoning and does not account for either unconscious influences on behaviour or the role of emotions beyond those related to expected outcomes. These factors critically limit the utility of the TPB when exploring healthcare provider behaviours, where we expect both unconscious behaviours (Sax & Clack, 2015) and emotions (Loveday, Lynam, Singleton, & Wilson, 2014; McLellan et al., 2016) to play a role in HCP infection prevention behaviours. Based on these limitations, it is likely that the field of infection could further benefit from the application of more comprehensive behaviour change theories incorporating constructs beyond those in the TPB.

1.2.2.3. Theoretical domains framework

In light of the vast array of psychological theories and associated explanatory constructs available to understand and explain behaviour change, an overarching theoretical framework based on expert consensus has been proposed, titled the "Theoretical Domains Framework" (TDF) (Michie et al., 2005). The first version of the TDF (TDFv1) consolidates 128 constructs from 33 behaviour change theories into 12 theoretical construct domains. These 12 domains include: 1) Knowledge; 2) Skills; (3) Social/Professional Role and Identity; (4)

Beliefs about Capabilities; (5) Beliefs about Consequences; (6) Motivation and Goals; (7) Memory, Attention, and Decision Processes; (8) Environmental Context and Resources; (9) Social Influences; (10) Emotion; (11) Behavioural Regulation; and (12) Nature of the Behaviours. A second version of the TDF (TDFv2) was later presented as a refinement of the original framework (Cane, O'Connor, & Michie, 2012). The refined TDFv2 framework saw the addition of three domains ('Optimism', 'Reinforcement', and 'Intentions') and removal of the domain, 'Nature of the behaviour', for a final 14 domains of theoretical constructs. The goal of the TDF is to integrate existing theories of behaviour change into a single framework to assess behaviour change topics, such as the implementation of evidence-based practices into healthcare (Cane et al., 2012). The TDF is specifically designed to aid researchers by providing a comprehensive, theory-based list of factors likely to influence behaviours (Atkins et al., 2017). In addition to cognitive and affective factors related to individual motivation, the TDF also includes factors related to the physical and social environment that are likely to influence behaviour. It is important to note that the TDF is not a theory that provides concrete and testable relationships between elements. Rather, the TDF is a theoretical framework that provides, "a theoretical lens" through which to view the factors that influence behaviour (Atkins et al., 2017). Because of the comprehensive scope of the TDF and the fact that it was originally developed to address implementation and behaviour change questions dealing with HCP in the healthcare field, the TDF was selected as a sensitising framework to guide the empirical and theoretical inquiry into behavioural determinants in this thesis. Another advantage of the TDF, as will be discussed later in this thesis, is that it has been linked, based on expert consensus, to established behaviour change techniques that are likely to address the barriers and enablers within specific TDF domains.

1.2.2.4. Theory-based interventions

Some evidence suggests that interventions designed with theoretical justification may be more effective in achieving sustained behaviour change (Noar & Zimmerman, 2005) and it is increasingly acknowledged that theory should play a central role in the design of behaviour change interventions (Craig et al., 2008; Michie et al., 2008). This thesis thus aims to contribute to the theoretical understanding of what works, for whom, when, and where, for changing healthcare provider behaviours to support patient safety and infection prevention, thereby laying the ground for the future design of theory-based infection prevention initiatives.

The need for such work has been acknowledged. A 2004 systematic literature review evaluated evidence from 235 randomized, controlled, studies (RCTs) and found that interventions to increase HCP adherence to evidence-based practice had only modest success (Grimshaw et al., 2004). Furthermore, a follow-up review on the use of theory in those 235 studies found that a majority of the studies lacked any theoretical foundation, thereby preventing the authors from being able to identify the basis of effective interventions (Davies, Walker, & Grimshaw, 2010).

Operational guidance about how to develop effective interventions that bridge the gap between practice and evidence has proposed the following steps: identify and define the behavioural problem; perform a behavioural analysis that identifies barriers and enablers needing to be addressed; identify possible solutions by selecting interventions that address the modifiable barriers and enhance the enablers; and evaluate the chosen intervention (Figure 4) (French et al., 2012).

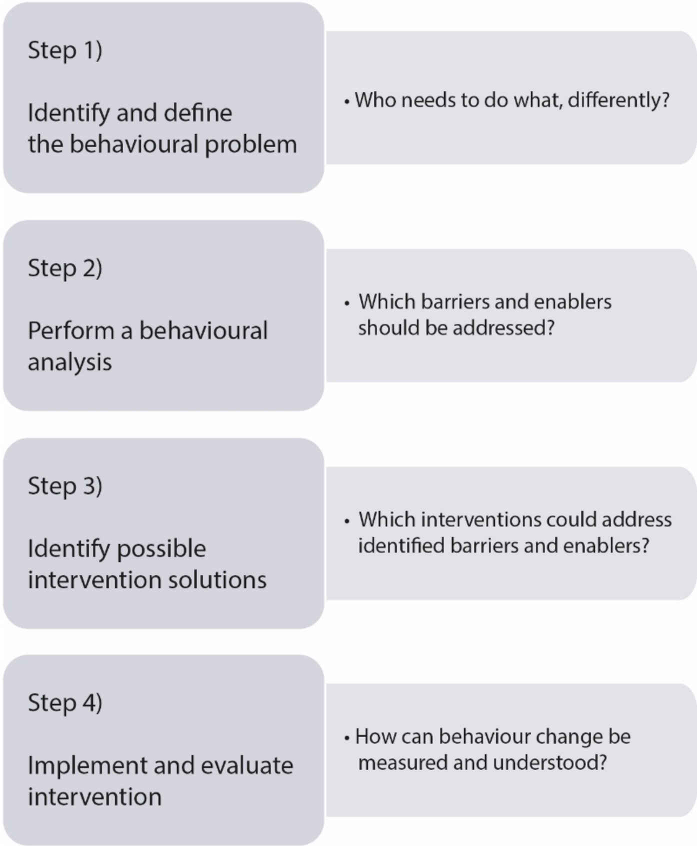

Figure 4: Steps to designing theory-based behaviour change interventions.

Designing behaviour change interventions must begin with a clear specification of the desired target behaviour. Because resources are limited, the behaviours targeted for intervention should be prioritised. This prioritisation may be based on targeting behaviours that are most likely to have an impact on the desired outcomes, as well as those behaviours that are most likely to be amenable to change. Once the relevant behaviours have been identified, the next step is to conduct a behavioural analysis to understand the factors that influence these behaviours, termed the behavioural determinants. Approaches for identifying behavioural determinants may be inductive, using empirical methods to explore relevant barriers and enablers that influence the behaviour of interest. Alternatively, behavioural analysis could be informed deductively based on established literature and theories. Behaviours do not occur in a vacuum; rather they occur within the context of other behaviours and other individuals acting as part of a larger system. Behavioural analysis should thus take into account the influences on behaviour within the context of the larger behavioural system. Finally, interventions to address specific behaviours should be designed using intervention functions that specifically target the identified behavioural determinants. Once these interventions have been implemented, their effectiveness should be assessed. This overall approach has been proposed specifically to accompany the TDF and provide practical guidance about how to incorporate theory into the development of complex interventions in healthcare (Michie et al., 2005; French et al., 2012). Use of the TDF is specifically proposed during step 2, using a theoretical framework to identify the whole range of barriers and enablers that need to be addressed to support behaviour change.

A similar approach for identifying and developing theory when designing interventions has been proposed as part of a larger framework to guide development and evaluation of complex interventions specifically for the healthcare context. (Campbell et al., 2000; Craig et al., 2008). During the intervention development stage, this guidance proposes a thorough evaluation of existing evidence, followed by developing a strong theoretical understanding of the likely process of change. The theoretical understanding may be based on existing evidence and theory, or where necessary, supplemented by new primary research.

Building on the systematic approaches described above, this thesis proposes a three-part behavioural science paradigm using the TDF as a guideline framework specifically intended to guide infection prevention efforts. These steps and how they relate to the “infectious risk moments” approach is discussed in the next section.

1.3. INFECTIOUS RISK MOMENTS APPROACH

Building on existing approaches to incorporate theory into the development of complex interventions discussed in the previous chapter, this thesis proposes a behavioural science paradigm specific to the field of hospital infection prevention, intended to guide behaviour change efforts in this field.

Specifically, this thesis presents an “infectious risk moment” (IRM) approach that is grounded in this behavioural science paradigm to guide infection prevention efforts, as depicted in Figure 5.

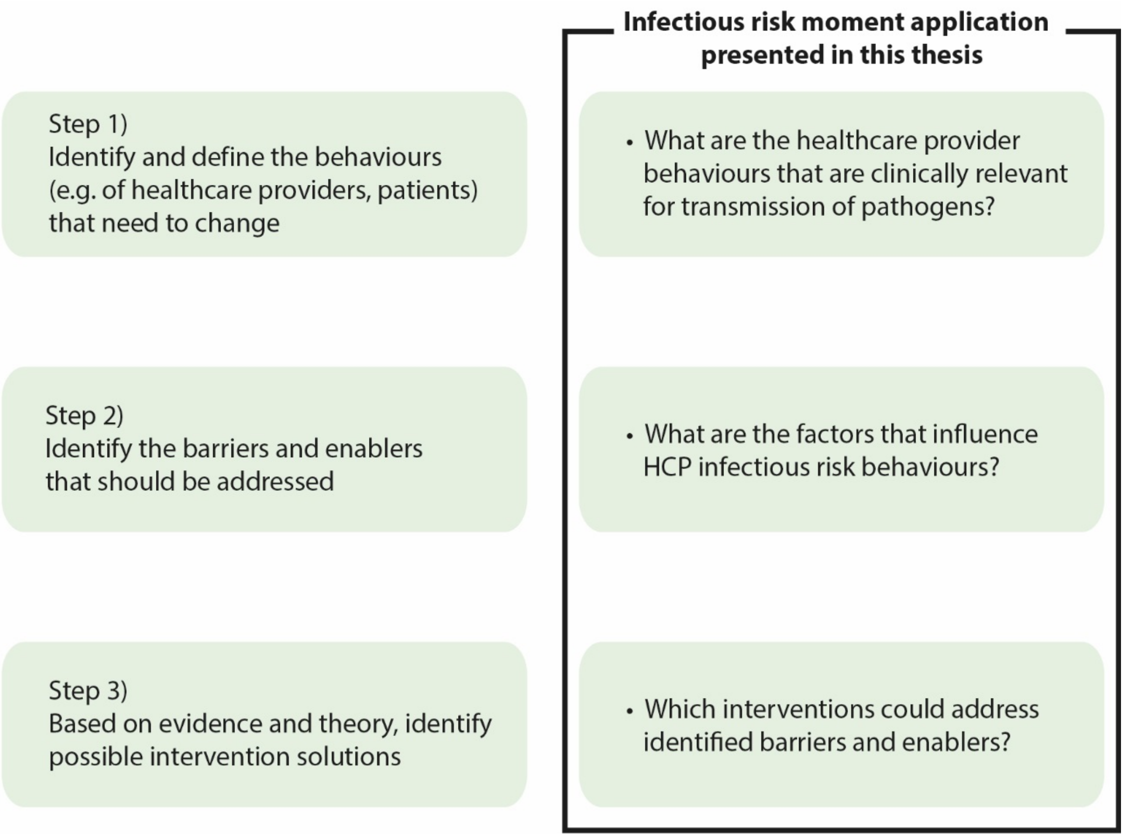

Figure 5: Behavioural science paradigm applied to infection prevention

The IRM approach is designed to address two primary gaps in the literature. First, the IRM approach considers a wide range of behaviours that are likely to be involved in the transmission of microorganisms that can cause patient infection, thus going beyond existing indications for hand hygiene. Instead of a rule-based approach based on existing guidelines, this thesis presents a novel, primary analysis of behaviours potentially relevant to patient infection, and assesses their frequency and clinical relevance based on expert opinion. Second, the IRM approach uses both empirical and theoretical methods to understand the factors that influence HCP behaviours in the context of providing patient care.

The work presented here addresses the first two steps of the approach shown in Figure 5, and provides guidance on how to approach the following step, of designing interventions.

Step 1: Identify and define the behaviours relevant to infectious risk. The design of effective behaviour change interventions must begin with a precise definition of the behaviour(s) that should be changed. In the field of infection prevention, hand hygiene has been the primary focus of behavioural interventions. However, evidence suggests that other HCP behaviours may also be relevant to the transmission of microorganisms that cause infection. Typical infection prevention efforts are rule-based and aim to assess or increase compliance with existing guidelines. However, these guidelines may vary across institutional or regional settings and may not cover all behaviours that are actually relevant to the local risk of patient infection. Rather than taking a rule-based approach that would be limited to the content of local guidelines, this thesis presents a primary analysis of infectious risks based on exploratory assessment of local risks. This thesis thus begins with a systematic identification and classification of behaviours that may be related to infectious risks, termed “infectious risk moments” (IRM), that could potentially be the target of behavioural interventions.

It is critically important for healthcare systems to make informed decisions about how to direct education and resources. Given that numerous HCP behaviours may be linked to infectious risks, a method is needed to prioritise which behaviours should be the target of intervention. This thesis proposes a quantitative approach to risk assessment based on 1) the frequency with which infectious risk moments occur and 2) their clinical relevance as assessed by an international group of experts.

Step 2: Identify the factors that influence HCP infectious risk behaviours. Before designing interventions to reduce infectious risk behaviours, the factors that influence these behaviours must be thoroughly understood. It is important to recognize that behaviours relevant to infectious risks occur in the context of a complex healthcare environment. This thesis thus proposes multiple empirical methods for examining the factors that influence infectious risk behaviours while taking this context into account. A systematic literature review is also presented as a complementary method to identify and synthesise barriers and enablers to HCP compliance with established infection prevention measures. The TDF serves as both a sensitising and guideline framework throughout the studies conducted during step 2.

Step 3: Identify and prioritise possible intervention solutions. The results of this thesis have important implications for the design of infection prevention efforts in general and for those specifically targeting infectious risk moments. The implementation and evaluation of infection prevention interventions will be the topic of future research stemming from the results presented in thesis. These implications and future steps will be presented in the general discussion.

1.4. RESEARCH QUESTIONS AND STUDIES

To address the two primary research questions, eight interrelated studies were conducted. The outcome of each study informed the subsequent studies, as demonstrated in (Figure 6).

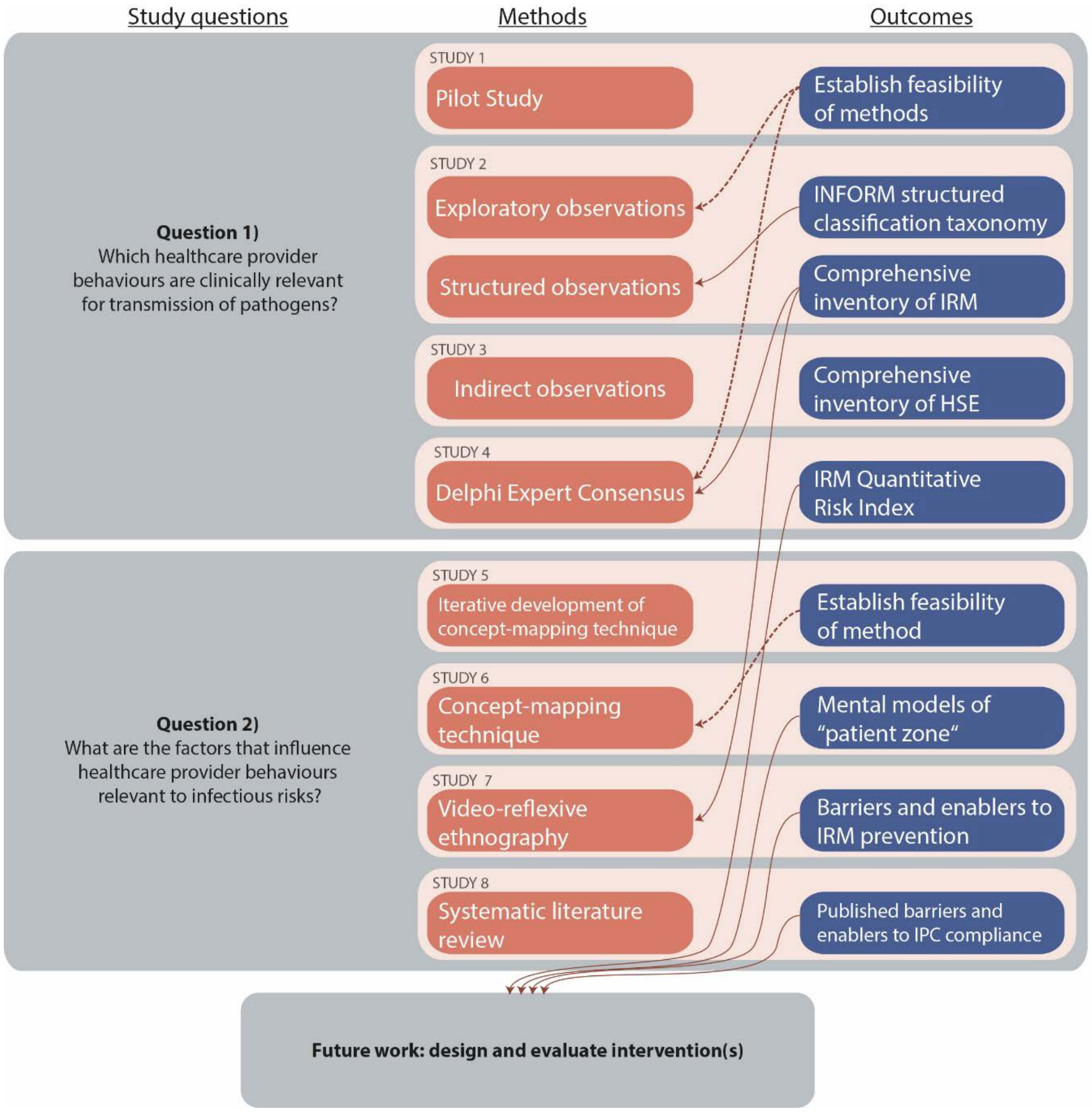

Figure 6: Overview of study questions, methods, and outcomes per paper

Figure 6 legend: IRM, infectious risk moments; HSE, hand-to-surface exposures

Q1. Which healthcare provider behaviours are clinically relevant for transmission of pathogens?

Addressing this first research question necessitated the development of methods to identify, classify, and quantify infectious risk behaviours. These are detailed here as sub-questions.

These closely interrelated sub-questions were addressed stepwise throughout the 8 papers/studies reported in this thesis, as depicted in Figure 6.

Q1.1. How can behaviours that are relevant to the transmission of pathogens be identified?

This thesis began with a pilot study, reported in Paper 1 (section 2.1) that aimed to assess the feasibility of identifying infectious risk moments through direct exploratory observations then assess clinical relevance using expert consensus. The outcome of the pilot study was to establish the feasibility of this approach in a sample population based on 30 hours of observation in one intensive care unit. Paper 2 then reports on a more extensive study including 130 hours of exploratory observations in three unique care settings (intensive care, medical ward, emergency ward) to identify behaviours potentially involved in the transfer of pathogens to patients.

Q1.2. How can behaviours relevant to the transmission of pathogens (IRM) be classified?

Building on the 130 hours of exploratory observations reported in Paper 2, a framework was established for classifying IRM based on the surfaces involved in the transmission pathway, i.e. the source, vector, and endpoint of pathogens being potentially transmitted. This framework, entitled, “infectious risk moment classification taxonomy (INFORM)”, is presented in Paper 2.

Q1.3. How can behaviours relevant to infectious risk be quantified, and how frequently do these occur in various healthcare settings?

Using the INFORM classification taxonomy, 54 hours of structured observations were conducted to quantify how frequently different types of IRM occurred in three care settings. These observations led to the establishment of IRM frequency overall, and in each care setting. In a parallel stream, Paper 3 reports on a complementary method using indirect observations with a head-mounted camera to identify and quantify behaviours relevant for transmission. In contrast to the IRM studies reported in papers 1, 2, and 4, study 3 focuses exclusively on the role of HCP hands in the potential transfer of pathogens via their frequent contacts with surfaces throughout the healthcare environment. Similar to the IRM studies, the approach presented in study 3 was not limited to existing indications for hand hygiene. Rather, all hand-to-surface exposures (HSE) were systematically observed and quantified. Together, studies 2 and 3 represent complementary methods for assessing the frequency and nature of infectious risk behaviours.

Q1.4. How clinically relevant are IRM for patient safety?

In the absence of conclusive microbiological studies to indicate the likelihood of microorganism transfer associated with observed IRM, paper 4 reports on an expert consensus study to assess clinical relevance of IRM. The study employed a modified Delphi processes over three survey rounds, where experts in microbiology, infectious diseases, and infection prevention and control indicated how likely different IRM were to be associated with patient outcomes of colonisation or infection. These expert likelihood ratings were mapped against frequency data from the structured observations (paper 2), resulting in a quantitative indication of clinical relevance for each identified IRM, also reported in paper 4. This quantitative risk index is proposed as a tool for assessing clinical relevance of IRM and informing the prioritisation of infectious risks to be addressed by future interventions.

Q2. What are the factors that influence healthcare provider behaviours relevant to infectious risks a) in general and b) specific to identified "infectious risk moments"?

Multiple empirical and theoretical methods were explored during this thesis for identifying behavioural determinants. These methods were developed and applied over multiple studies to address the following sub-questions.

Q2.1. How can we identify mental models of healthcare providers?

Individual mental models, also described as “small-scale models of reality”, can be defined as internal mental representations or thought processes that a person has about how things work (Craik, 1943b). They are based on experiences in the real world, and have been suggested to play an important role in individual cognition (Johnson-Laird, 1983, 2006). Individual mental models about how things work are reflections of that individual’s beliefs, but these beliefs may be flawed or inaccurate, leading to undesired or unsafe behaviours. Mental models have further been proposed as a useful concept for understanding HCP infection prevention behaviours (Sax & Clack, 2015). Because mental models are a largely subconscious phenomenon, they cannot simply be identified by asking individuals about them directly. Study 5 thus reports on the iterative development and testing of a methodology for identifying HCP mental models relevant to infectious risks. The study employs a concept-mapping exercise based on a card-sorting technique together with a think-aloud protocol.

Q2.2. What are the mental models that healthcare providers have regarding the patient zone?
The “patient zone” is an infection prevention concept that was established together with the “my five moments for hand hygiene” (Sax et al., 2007). The patient zone concept proposes a geographical distinction between objects in the healthcare environment that are likely to be contaminated primarily by patient flora (i.e. “inside” the patient zone) and those that are likely to be contaminated by flora from the larger healthcare environment (i.e. “outside” the patient zone). Conceptually, the goal of the patient zone concept is to create a geographical distinction between a patient’s own direct environment, and other items that are likely to be contaminated by microorganisms that are foreign and potentially harmful to the patient. For hand hygiene, this implies that hands should be disinfected when entering or leaving the patient zone, to prevent that patients are exposed to harmful microorganisms from the healthcare environment or that patient microorganisms contaminate the wider healthcare environment, respectively. Although the patient zone concept was initially introduced in the

context of hand hygiene guidelines, it became clear during the observational studies included in this thesis that individual perceptions about what items belong inside versus outside of the patient zone have important behavioural indications beyond hand hygiene. Study 6 employs the methodology established in study 5 to explore HCP mental models about the patient zone.

Q2.4. What are the factors that influence healthcare provider behaviours specific to identified infectious risk moments?

Study 7 uses video-reflexive ethnography to identify and understand the factors that influence HCP IRM behaviours. Video-reflexive ethnography is a relatively novel qualitative research technique that involves filming HCP while providing direct patient care, then reviewing the care film together with the filmed HCP during a reflexive interview session (Carroll, Iedema, & Kerridge, 2008). Study 7 reports the results of 40 reflexive interviews conducted in the same three care settings in which IRM were observed. The theoretical domains framework (TDF) served as a sensitising framework to guide the semi-structured interviews, and as a coding framework to deductively code the verbatim interview transcripts. This qualitative analysis is currently ongoing, and preliminary results are presented.

Q2.4. What are the barriers and facilitators to healthcare provider compliance with infection prevention guidelines based on published literature?

Study 8 reports the preliminary results of an ongoing systematic literature review on the barriers and facilitators to compliance with existing infection prevention guidelines. All studies using qualitative research methods to explore barriers and facilitators to guideline compliance were included in the review. All barriers and facilitators reported in the included studies were extracted and the TDF was further used as a framework for this secondary data analysis. The results of this theoretically informed evidence synthesis complement the findings of the empirical methods reported in Studies 5-7.

2. CHAPTER 2: PROOF OF CONCEPT, PILOT STUDY

In the following chapter, a pilot, proof of concept study is presented. The goal of this study was to assess the feasibility of exploratory and structured observations for identifying infectious risk moments and to pilot the Delphi methodology for conducting an expert consensus study.

2.1. STUDY 1: INFECTIOUS RISK MOMENTS: A NOVEL, HUMAN FACTORS-INFORMED APPROACH TO INFECTION PREVENTION.

Lauren Clack, Jan Schmutz, Tanja Manser, & Hugo Sax

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ABSTRACT

Background. In spite of significant progress in the field of infection control, rates of preventable healthcare-associated infections (HAI) remain high. So far, interest usually focuses on procedures associated with high likelihood of HAI in case of procedural non-compliance or hand hygiene. We present a human factors-informed concept suggesting that infectious risk lies in a wide range of in seemingly low-risk, yet frequent care manipulations referred to as infectious risk moments (IRM). We performed a pilot study to validate this concept.

Methods. Potential IRMs were noted during semi-structured observations in an intensive care unit. A panel of infectious disease/control experts then rated the identified IRM for likelihood of an infectious outcome, either colonization with multiresistant organisms (MDRO) or HAI, using an adapted Delphi Method.

Results. Overall, 28 distinct potential IRMs were identified during 30 hours of observation and categorized according to association with hand hygiene, glove use, or surfaces of inanimate objects. Likelihood for colonization with MDRO was rated higher than for HAI, while frequency of IRM was estimated to be variable between less, equal or more than hourly.

Conclusions. This pilot study confirmed our hypothesis that a wide range of IRM can be observed during routine patient care. They are frequent and associated with low likelihood density for infection. Once established by a larger study, a comprehensive IRM inventory may embody system-wide infectious risk and provide a meaningful standardized taxonomy for research, training, and intervention.

BACKGROUND

Healthcare-associated infections (HAI) are a major threat to patient safety on a global level (Allegranzi et al., 2011). Repeatedly, scientific publications report extraordinary reductions of HAI rates in areas such as central line-associated bloodstream infections, ventilator associated pneumonias, and urinary tract infections (Eggimann et al., 2000; Stephan et al., 2006; Bouadma et al., 2010a; Bouadma et al., 2010b). Almost exclusively, these interventions target procedures with high per-procedure likelihood of HAI in case of procedural non-compliance.

Hands of healthcare workers (HCW) are the most common vehicles for transmission of pathogens in hospital settings (Pittet et al., 2006a). Thus, hand hygiene has been widely accepted as the leading measure for preventing HAI (Pittet et al., 2009). Each *individual* hand hygiene indication, however, represents a low-likelihood opportunity for transmission. Instead, the substantial overall risk lies in the *cumulative* high frequency of hands touching surfaces and patients, successively.

While hand hygiene is certainly a crucial measure to prevent transmission of HAI, evidence suggests that transmission and infection occur due to additional unsafe moments during care (Bonten et al., 1996; de Gialluly et al., 2006; Hill, King, & Day, 2006; Huang, Mehta, Weed, & Price, 2006a; Huang, Datta, & Platt, 2006b; Schabrun & Chipchase, 2006; Youngster, Berkovitch, Heyman, Lazarovitch, & Goldman, 2008). In consequence, we propose a novel, human factors-informed infection control and prevention concept. This concept suggests that infectious risk resides to a considerable proportion in seemingly innocent, but frequent, care-related manipulations at ‘infectious risk moments’ (IRM) that include, yet go beyond, indications for hand hygiene (**Box 1**). We do this in the line of thought that led to the creation of the ‘My five moments for hand hygiene’ concept (Sax et al., 2007), utilizing human factors principles to incorporate a systems approach and increase chances for effectiveness and implementation success. Human factors is the interdisciplinary field that aims to optimize interactions between humans and their work environment in order to minimize errors, promote human well-being, and ultimately improve overall system performance (http://www.iea.cc/whats/index.html) (Walton et al., 2010).

Box 1. Definition of Infectious Risk Moments (IRM)

Infectious Risk Moments (IRM) are time spans in the workflow of healthcare workers (HCW) that are associated with a risk of patient colonization or infection. At any single IRM, healthcare worker behaviour may be safe or unsafe. When HCW display safe behaviours at IRM, they mitigate the risk, however when HCW behaviour is unsafe, the likelihood for an infectious outcome increases. We distinguish the two infectious patient outcomes, colonization-usually with multi-resistant pathogens-and infection.

This pilot study was conducted in a cardio-vascular intensive care unit (ICU) at the University Hospital of Zurich. The goal was to test the feasibility of identifying and rating the risk associated with potential IRM according to frequency of IRM occurrence and the associated likelihood of an infectious patient outcome, i.e. colonization or infection.

METHODS

We chose a three-step approach to identify and validate IRM. First, the research team went through a sensitizing process concerning infectious risks (Blumer, 1954). Second, potential IRM were identified through semi-structured observations. Third, an expert panel rated the likelihood of infectious patient outcomes of the collected IRM using an adapted Delphi Method (Gordon & Glenn, 1994).

Sensitizing. The research team, consisting of two human factors researchers with extensive experience in qualitative and quantitative observation in healthcare (LC, JS), held several rounds of discussion with a senior infectious diseases clinician (HS), and read a useful selection of core literature on this topic. The aim of this sensitizing process was to enable the observers to recognize a broad range of potential IRM during observations.

Observations. The scope of observations was to identify a comprehensive listing of potential IRM – deductively, based on known transmission pathways and infectious disease pathophysiology, and inductively, using a systems perspective to identify previously undetected risk moments in the workflow. The observers (LC, JS) spent ~20 hours each conducting observations in the ICU. They took notes during the sessions and transcribed potential IRMs as short narratives (**Table 1**). IRM were collected independently of safe or unsafe healthcare worker (HCW) behaviour. Sessions typically lasted 2-3 hours. The first five of twenty hours served as time for the ICU staff to become accustomed to the presence of the observers, thereby diminishing the Hawthorne effect (Atkinson, 1987) and allowing observers to gain understanding of care processes in this specific ward. After each observation session, results were discussed among the researchers to guarantee common understanding of the IRM concept. The observers sought a broad variety of care scenarios, typically including such activities as patient arrivals from the operating theatre, in- and extubations, ultrasound examinations, and dressing changes. Following the observations, the researchers established a categorical frequency estimate for each IRM (occurring less than hourly, approximately hourly, more than hourly).

Risk Rating of IRMs. We chose an adapted Delphi-Method(Gordon & Glenn, 1994) to establish the likelihood for infectious patient outcomes of each observed IRM, separately for *colonization* with multi-resistant microorganisms and *infection*. A purposeful sample of 9 infectious diseases and infection control clinicians from our Division with at least 3 years of specialized experience served as expert panel. First, panel participants independently rated each potential IRM on a gradual five-item likelihood scale ranging from 0 (‘nil’) to 4 (‘very high'). Then all results were compared during a group meeting and inconsistencies between experts were discussed until consensus was reached.

The Ethics Review Board of the State of Zurich formally waived the necessity for a full ethics review due to the quality improvement approach of this assessment (KEK-StV-Nr. 06/13).

RESULTS

Observations resulted in 28 distinct potential IRM. We distinguished three categories for IRM, namely those associated with hand hygiene, glove use, or objects. **Table 1** provides the full list of observed IRM and their corresponding likelihood rating and frequency estimate. The Delphi process resulted in an overall mean rating of 0.93 *(SD*, 0.74*)* for the likelihood of infection and 1.87 *(SD*, 1.04*)* for the likelihood of colonization with multi-resistant microorganisms. Overall, the likelihood rating for colonization was higher than for infection, the latter being rated 'nil' in 8 cases. Three potential IRM received the rating 'nil' for both, colonization and infection, and consequently did not qualify as IRM. **Figure 7** displays the distribution of all validated IRM in a frequency/likelihood matrix.

Table 1: Infectious Risk Moments (IRM) with likelihood rating and frequency estimate

Infectious Risk Moment[1]	Likelihood of transmission of MDR microoganisms[2]	Likelihood of HAI[2]	Frequency of occurrence[3]
Hand hygiene			
Approaching patient with a new infusion bag without hand hygiene, then connecting the bag to a vascular access line	●●●○	●●○○	++
Rubbing one's own nose then touching a patient without intermittent hand hygiene	●●●○	●●○○	+++
Dropping a bottle from beside table of a patient, then putting it back without cleaning. Later another healthcare worker (HCW) touches the bottle then the patient without hand hygiene in-between	●●○○	●○○○	+
Wiping the mouth of a coughing patient, then connecting a new infusion bag without hand hygiene	●●○○	●○○○	+
Inserting a feeding tube through the nose of patient, then touching the patient and patient surroundings (i.e., monitor and bedside table) without hand hygiene	●●○○	●○○○	+
Alternating between touching a bedside touchscreen and touching a patient without hand hygiene given the fact that the chart is frequently touched by other healthcare workers coming from the hospital environment (e.g. to silence an alarm) without hand hygiene	●●○○	●○○○	+++
Alternating between writing in a patient chart and touching a patient without hand hygiene, given the fact that the chart is frequently touched by other healthcare workers coming from the hospital environment without hand hygiene	●●○○	●○○○	+++
Touching a bedrail and then the patient without hand hygiene after another HCW coming from the hospital environment touched the bedrail without prior hand hygiene	●●○○	●○○○	++
Wheeling an ultrasound machine next to a patient bed, then alternating between using the machine's keyboard and the patient's abdomen without intermittent hand hygiene	●●○○	●○○○	+
Leaving a patient to get a dressing, cutting it to the right size outside the patient zone, then returning to the patient and applying the dressing to the patient, all without hand hygiene	●●○○	●○○○	++
Touching one's private mobile phone then a patient without intermittent hand hygiene	●●○○	●○○○	+++
Using a private pen for a note, then touching a patient without intermittent hand hygiene	●●○○	●○○○	+++
Touching one's own eyes then a patient without hand hygiene	●●○○	●○○○	+++
Displacing a towel covering a patient from one body site to another without prior hand hygiene	●●○○	○○○○	+
Leaving a patient to get a new towel from the closet, applying it to the patient without hand hygiene	●○○○	○○○○	++
Touching the shoulder of a colleague during a discussion, then touching a patient without hand hygiene	●○○○	○○○○	++
People bumping into each other due to restricted space while caring for a patient, then touching the patient	●○○○	○○○○	++
Touching a patient's monitor after contact with another patient without hand hygiene in-between	○○○○	●○○○	+++
Gloves			
Three HCWs transporting a patient from the operating theatre arrive with gloves on. They proceed to install the patient – connecting medication, infusion, and ventilation without any change of gloves.	●●○○	●○○○	++
Three HCWs transporting a patient from the operating theatre arrive with gloves on. They proceed to install the patient – connecting medications, infusions, and ventilation without any change of gloves and also touch the central venous line insertion site	●●●●	●●●○	+
Three HCWs transporting a patient from the operating theatre arrive with gloves on. They proceed to install the patient – connecting medication, infusion, and ventilation without any change of gloves and also accidently touch the connection points of the ventilator tubes	●●●○	●●○○	++
Disinfecting donned gloves before touching a patient[4]	○○○○	○○○○	+
Object handling			
Using an ultrasound scanner head on consecutive patients without cleaning	●●●●	●○○○	+
Reconnecting Y-tube of ventilation circuit after it fell to the floor without cleaning	●●●○	●●○○	+
Infusion tubes falling to the ground while being connected to a patient during arrival, then consequently being put back on the bed without cleaning	●●○○	●○○○	++
Dropping a bottle from a patient table and placing it back without cleaning	●●○○	●○○○	+
Placing bed linens (or other patient belongings) on a windowsill and them to the patient (NB: HCWs often sit on the ledge in times of less workload)	●○○○	○○○○	++
Putting a towel on the bed for a while after having it used on the patient[4]	○○○○	○○○○	++
After attending to an influenza patient isolated for droplet precautions, removing one's gown and shaking it out near the patient before folding it. [4]	○○○○	○○○○	+

[1] Note: To make likelihood of infectious patient outcome clear to the rating experts, IRM were always indicating unsafe behavior.

[2] Likelihood rating for infectious patient outcomes according to Delphi process with 9 Infectious Diseases/Infection Control experts: ○○○○, nil; ●○○○, low; ●●○○, medium; ●●●○, high; ●●●●, very high

[3] Semi-quantitative rating of observed frequency: +, less than hourly; ++, hourly; +++, more than hourly

[4] Likelihood rating being nil for both infectious outcomes, these potential IRM were not retained as such (text in italics).

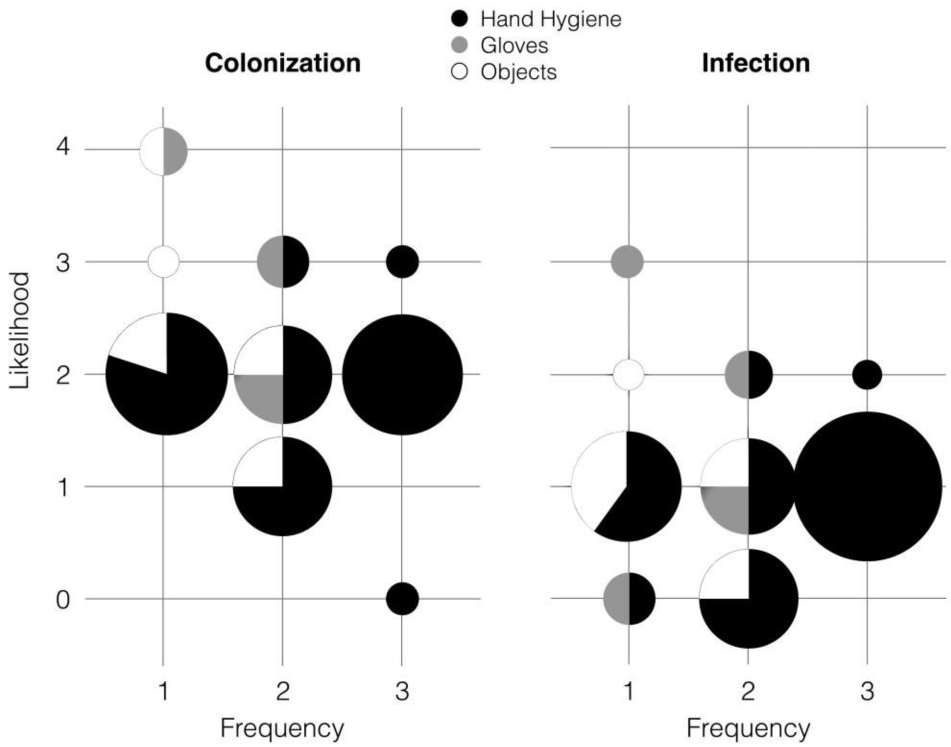

Figure 7 Likelihood/Frequency Matrix for Infectious Risk Moments

Figure 7 Legend: Frequency, semi-quantitative rating of observed frequency: 1, less than hourly; 2 ≈ hourly; 3, more than hourly. Likelihood, likelihood of an infectious patient outcome, i.e. colonization or infection: 1, low; 2, medium; 3, high; 4, very high; classification of IRM: black, hand hygiene; dark grey, glove use; light grey, objects/cleaning; number of distinct observed IRM are represented by the diameter of the pie charts.

DISCUSSION

In line with our hypotheses, experts rated the likelihood of infectious outcome due to unsafe behaviour at IRM mostly low, with lower likelihood of infection than colonization. As illustrated by the likelihood/frequency matrices, the cumulative risk of negative outcomes following these seemingly harmless manipulations becomes substantial due to their high frequency. While this concept is not new in other fields concerned with risk management (Slovic, 2000), to our knowledge this is the first time such an approach has been applied to infection control. It is a complementary addition to the classical infection control *hot spots* associated with a higher risk density, such as the insertion of central venous or urinary catheters.

This study demonstrated that IRM go beyond established indications for hand hygiene, to include moments when glove use and interaction with physical objects may be associated with infectious outcomes. These dimensions have not previously been included in an overarching concept (Bonten et al., 1996; de Gialluly et al., 2006; Hill et al., 2006; Huang et al., 2006a; Huang et al., 2006b; Schabrun & Chipchase, 2006; Youngster et al., 2008). The resulting IRM concept reflects the overall microbiological risk of a care environment and its behavioural dimension from a system-wide perspective. This is of practical value in various ways.

A comprehensive IRM inventory provides a basis for further patient safety initiatives. Educational interventions would most likely benefit from a systematic taxonomy, helping to establish a more global perception of infectious risks in patient care. Increasing attentiveness to safe behaviours IRM at would likely also indirectly improve other infection control practices.

Most importantly, the IRM concept provides practical opportunities through understanding of risk perception. Risk is typically defined as a product of the likelihood of an event and the magnitude of its consequences (Kasperson et al., 1988). As such, the risk value of low-consequence/high-probability and high-consequence/low-probability may be equivalent. We did not address the magnitude of consequences, but estimated instead the frequency at which the IRM occurs. An IRM of high-frequency/low-likelihood and low-frequency/high-likelihood would possess similar probability of infectious patient outcome. If HCWs perceive only the risk associated with isolated IRMs, they will underestimate the overall consequences of unsafe behaviour. The IRM concept lays the groundwork for future inquiry into HCW perception of risk and determinants of behaviour at these moments in order to ultimately inform tailored interventions.

Several limitations apply to this study, due largely to the fact that it was designed as a pilot to assess the feasibility of a larger project. The IRM so far reflect a specific setting based on limited observations. Sampling saturation has neither been sought nor reached. Additional IRM may be identified with extended time in the field and inclusion of additional settings. Moreover, while IRM frequency was only estimated, a future study would include structured quantitative observations to measure IRM frequency. Finally, the risk rating was limited in participants and cycles, and as mentioned before, the panel did not evaluate the magnitude of negative consequences following unsafe behaviour during IRM.

Other challenges are intrinsic to this type of research and will persist in a larger study. Data collection by human beings is subject to individual bias and pre-existing mental models. Involving multiple observers, investing in a trial observation period with frequent discussions and a special focus on reflexivity certainly helped to mitigate this potential bias (Gurses, Murphy, Martinez, Berenholtz, & Pronovost, 2009). Further, the lack of microbiological investigation in this study could be considered a limitation. Such testing, however, would be unfeasible given the vast number of variables that would need to be considered in the given scenarios. In light of this challenge, others investigating the transmission of infectious diseases in hospital settings have turned to agent-based modelling and simulations (Barnes, Golden, & Wasil, 2012). For our pilot study, we have looked to specialists in this domain to provide expert assessment of such risks.

In conclusion, this pilot study confirmed our hypothesis that a wide range of IRM can be observed during routine patient care. The majority of IRM concerned moments of hand transmission, but were also linked to glove use and surfaces of inanimate objects. Based on these results, a comprehensive IRM inventory appears feasible. Such an inventory together with the proposed conceptual underpinning may help advancing the field of infection prevention by providing a standardized taxonomy for research, training, intervention, and evaluation. A larger study is warranted to extend the present findings.

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COMPETING INTERESTS

The authors have no competing interests to declare.

CONTRIBUTORS

LC and JS performed data collection for this study and drafted the initial manuscript. All authors contributed to study design and data analysis and reviewed and edited the manuscript.

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3. CHAPTER 3: METHODS FOR OBSERVING INFECTIOUS RISK BEHAVIOURS

In the following chapter, two studies are presented that take different approaches to identifying, classifying, and quantifying behaviours relevant for infectious risks.

The first study (Clack, Passerini, Wolfensberger, Sax, & Manser, 2018b) begins with direct exploratory observations to identify potential IRM and establish a taxonomy for classifying observed IRM. This taxonomy forms the basis of structured observations, during which the nature and frequency of IRM are observed in three distinct care settings: a medical ward, an intensive care unit, and the emergency ward.

The second study (Clack, Scotoni, Wolfensberger, & Sax, 2017) takes an alternative approach, using a head-mounted camera to indirectly observe all hand-to-surface contacts of nurses and physicians during direct patient care.

3.1. Study 2: Frequency and nature of Infectious Risk Moments during acute care based on the INFORM Structured Classification Taxonomy

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ABSTRACT

Objective. Establish a comprehensive inventory of infectious risk moments (IRM), seemingly innocuous, yet frequently occurring care manipulations potentially resulting in transfer of pathogens to patients. Develop and employ an observational taxonomy to quantify the frequency and nature of IRM in acute care settings.

Design. Prospective observational study and establishment of observational taxonomy.

Setting. Intensive care unit, general medical ward, and emergency ward of a university-affiliated hospital.

Participants. Healthcare workers (HCWs).

Methods. Exploratory observations were conducted until saturation to identify IRM, which were coded based on the surfaces involved in the transmission pathway, to establish a structured taxonomy. Structured observations were performed using this taxonomy to quantify IRM in all three settings.

Results. Following 129.17 hours of exploratory observations, identified IRM involved HCW hands, gloves, care devices, mobile objects, and HCW clothing and accessories. A structured taxonomy (INFORM) was established to classify each IRM according to the “source”, “vector”, and “endpoint” of pathogens. We observed 1,138 IRM during 53.77 hours of structured observations (31.25 active care hours) for an average density of 42.8 IRM/active care hour overall, and 34.9, 36.8, and 56.3 in the intensive care, medical, and emergency wards, respectively.

Conclusions. Hands and gloves remain among the most important contributors to transfer of pathogens within the healthcare setting, but medical devices, mobile objects, invasive devices, and HCW clothing and accessories may also contribute to patient colonization and/or infection. The INFORM observational taxonomy and IRM inventory presented may benefit clinical risk assessment, training and education, and future research.

INTRODUCTION

Healthcare-associated infections (HAI) remain a major threat to patient safety. A significant proportion of such infections are likely preventable through the application of infection prevention measures,(Harbarth et al., 2003; Umscheid et al., 2011; Zingg et al., 2015; Storr et al., 2017) such as those aiming to reduce the transmission of pathogens that may lead to patient colonization or infection.(Siegel et al., 2007) Hand hygiene, for example, is widely recognized as one of the most effective practices to reduce infection rates and patient colonization with multidrug-resistant bacteria by reducing transmission of microorganisms.(Allegranzi & Pittet, 2009) Strong evidence also suggests that environmental contamination of surfaces and objects contribute to HAI,(Bonten et al., 1996; Schultsz et al., 2003; Duckro, Blom, Lyle, Weinstein, & Hayden, 2005; Fawley, Parnell, Verity, Freeman, & Wilcox, 2005; Boyce, 2007; Weber, Anderson, & Rutala, 2013) yet the behavioral focus of such studies is often limited to hand hygiene and environmental cleaning. While the practice of hand hygiene has been increasingly studied over the last decade for its role in infection prevention, considerably less knowledge exists regarding other important infection-related behaviors.

A growing body of evidence suggests that practices beyond those addressed by hand hygiene may be relevant in the transmission of microorganisms resulting in patient colonization and infection – such as handling of mobile objects(Clack et al., 2014; Livshiz-Riven et al., 2015), healthcare personnel private(Lopez et al., 2009) and professional attire(Treakle et al., 2009; Wiener-Well et al., 2011), and medical devices.(Schultsz et al., 2003; Birnbach et al., 2015; Livshiz-Riven et al., 2015) We therefore hypothesize that an important portion of infectious risks lie at “infectious risk moments” (IRM) – seemingly innocuous, yet frequently occurring care manipulations potentially resulting in transfer of pathogens to patients – which include, yet go beyond, indications for hand hygiene.(Clack et al., 2014)

The design of infection prevention strategies that consider a broad range of infectious risks must begin with systematic identification and classification of such IRM. In a two-part project, we conducted 1) *exploratory observations* to establish a comprehensive inventory of potential infectious risk moments, which served as a basis for developing a taxonomy for structured observations and 2) *structured observations* to quantify the frequency and nature of IRM in three distinct typical healthcare settings.

METHODS

Design

We conducted a prospective observational study in two parts. First, we conducted live exploratory observations to identify a wide range of potential IRM and to establish a structured taxonomy (INFORM) for identifying and classifying IRM. Second, we conducted live structured observations based on the INFORM taxonomy. Parts of this methodology have been previously piloted. The observations reported in the current manuscript do not include the pilot observations.

Setting

An intensive care unit (ICU), general medical ward, and emergency ward including trauma unit located at a 900-bed, university-affiliated, tertiary care hospital were purposefully sampled to represent a broad range of care activities and potential infectious risks. All healthcare workers (HCWs) from the participating wards were included in the study. The study hospital has a well-established infection prevention and control (IPC) group with extensive state-of-the-art, written IPC standard operating procedures, weekly IPC rounds, and a designated IPC nurse consultant for each hospital ward.

Exploratory observations

Observers with background in nursing (CDA and VG) and human factors/psychology (LC) and extensive experience conducting observations for patient safety research carried out *exploratory observations* in all three settings. Field notes documented the care processes observed and any potential IRM – operationally defined as behaviors potentially resulting in the transmission of pathogens that may result in patient colonization or infection. The observers discussed all identified potential IRM regularly throughout the exploratory observation period together with a senior infection prevention physician (HS) and all potential IRM were collected in a database.

Based on the definition of IRM and following hand hygiene literature, IRM were limited to moments resulting in potential transfer of pathogens to patients and their immediate surroundings (e.g. bedding), rather than focusing on the larger translocation of microorganisms throughout the healthcare environment. For example, a HCW entering a patient room then, without doing hand hygiene, touching the patient's bedside monitor to silence an alarm – a behavior that occurs often and may introduce non-patient flora to the patient environment – was not considered an IRM. Only behaviors that resulted in potential transfer of pathogens directly to the patient were considered. We distinguished between *non-critical patient sites* (e.g. intact skin, intact dressings, patient clothing), *critical patient sites*, defined as "body sites or medical devices that have to be protected against micro-organisms potentially leading to HAI"(Sax et al., 2007) (e.g. mucous membranes, catheter insertion sites, open wounds), and *patient bedding*. Exploratory observations were conducted until saturation was achieved in each setting, i.e. no new IRM were observed.

Structured observation taxonomy and mobile observation tool validation

Following exploratory observations, all IRM were extracted from field notes and systematically coded according to the source, vector, and endpoint from, through, and to which pathogens were transferred, respectively. This structure was used to establish INFORM (INFectiOus Risk Moment classification taxonomy), on which structured observations were based (**Figure 8**). A mobile observation tool based on the INFORM taxonomy was programmed with Filemaker 14 (FileMaker, Inc., Santa Clara, CA). To ensure the quality of observations, two observers (LC, SP) validated the mobile observation tool during a one-month test period. Percent agreement between the two observers was calculated to measure sensitivity (detection of the same IRM) and Cohen's kappa was calculated to determine inter-observer agreement (consistent classification of IRM) using STATA (StataCorp, 2015).

Source	
(Source)	(Source detail)
Environment	Bedside Table, Curtains, Floor, Lamp, Outside Patient Room, Paper Patient Records, Partition Walls, Patient Bed, Trolley, Other
Gloves	HCW Gloves
Hands	HCW Hands
Healthcare Worker	Body, Clothing, Face, Hair, Other
Invasive Device	IV Tubes, Mechanical Ventilator, Suction Catheter, Other
Medical Device	Bedside Monitor, Blood-Pressure Cuff, Blood-Pressure Monitor, ECG, Infusion Pump, Non-Invasive Ventilator, Stethoscope, Thermometer, Ultrasound, Ventilator Monitor, X-Ray, Other
Mobile Object	Flashlight, Mobile Phone, Pen, Secretions, Tape Dispenser, Toilet Brush, Washcloth, Other
Other Patient	Critical Site, Environment, Intact Skin
Patient Critical Site	Airways, Bloodstream, Mucous Membrane Face, Mucous Membrane Genitals, Mucous Membrane Rectum, Open Wound, Uncapped CVC Hub, Uncapped IV Line, Urethra, Other
Patient Intact Skin	Contaminated Skin, Head, Lower Limbs, Trunk, Upper Limbs
Unknown Status	No Disinfection Observed

Vector	
(Vector)	(Vector detail)
Gloves	Don Gloves Without HH, Non-Sterile Gloves, Remove Gloves Without HH, Sterile Gloves
Hands	HCW Hands, Patient Hands
Healthcare Worker	Badge, HCW Private Clothing, HCW White Clothing, Watch
Invasive Device	Arterial Catheter Tip, CVC Tip, Invasive Ventilator, IV Tubes, Needle/Cannula, PVC Tip, Suction Catheter, Thoracic Tube, Uncapped Hub, Urinary Catheter Tip, Ventilation Filter, Other
Medical Device	Blood-Pressure Cuff, ECG, Infusion Pump, Non-Invasive Ventilator, Stethoscope, Thermometer, Ultrasound, X-Ray, Other
Mobile Object	Bedding, Dressing or Bandage, Flashlight, Medical Tape, Mobile Phone, Pen, Secretions, Tape Dispenser, Tourniquet, Transfer, Board, Transfer Cannula, Washcloth, Wristwatch, Other

Endpoint	
(Endpoint)	(Endpoint detail)
Critical Site	Airways, Arterial 3-Way Valve, Arterial Insertion Site, Arterial Lumen Port, Bloodstream, CVC Insertion Site, CVC Line 3-Way Valve, CVC Line-Infusion Connection, CVC Lumen Port, Feeding Tube, Mucous Membrane Face, Mucous Membrane Genitals, Mucous Membrane Rectum, Mucous Membrane Urethra, Open Wound, PVC Insertion Site, PVC Line 3-Way Valve, PVC Line-Infusion Connection, PVC Lumen Port, Urinary Catheter, Other
Non-Critical Site	Head, Lower Limbs, Trunk, Upper Limbs, Catheter Dressing, Patient Clothing, Wound Dressing, Other
Patient Bed	Bedding, Pillow

Figure 8: INFORM Infectious risk moment classification taxonomy

Figure 8 Legend: HCW=Healthcare worker, IV=Intravenous, ECG=electrocardiography, CVC=Central-venous catheter, PVC=Peripheral-venous catheter

Structured observations

Structured observations were carried out in the same three clinical settings using the mobile observation tool. Two observers (LC, SP) conducted live, structured observations in parallel to ensure systematic documentation of all IRM. Structured observations targeted periods of active patient care and both observers focused on the same single HCW at a time. Observation sessions of 30-60 minutes were deliberately conducted at different times throughout the workday to include many different HCW, who performed a diverse range of care tasks for multiple patients during each session. During live observations, both observers independently noted the source, vector, and endpoint of pathogens for each IRM according to the observational taxonomy as well as demographic information about the HCW being observed (i.e. gender, professional category), and contextual information (i.e. date, time, ward name, patient isolation status) using the mobile observation tool (**Figure 9**). No identifying patient or HCW information was collected during observations. For each observation period, we recorded the total amount of observation time, as well as the amount of active patient care time to calculate the density of IRM per setting. Following each structured observation session, all observed IRM were compared between the two observers and any discrepancies were discussed until a consensus agreement was achieved. Frequent discussion among researchers to achieve consensus after each observation period was maintained throughout the study to ensure quality and avoid drift between observers.

Ethics

The Cantonal Ethics Committee of Zurich (KEK-StV-Nr.73/14) formally waived the ethics requirement for this study. Participation in observations was voluntary and HCW were free to opt out or stop observations at any time without providing justification.

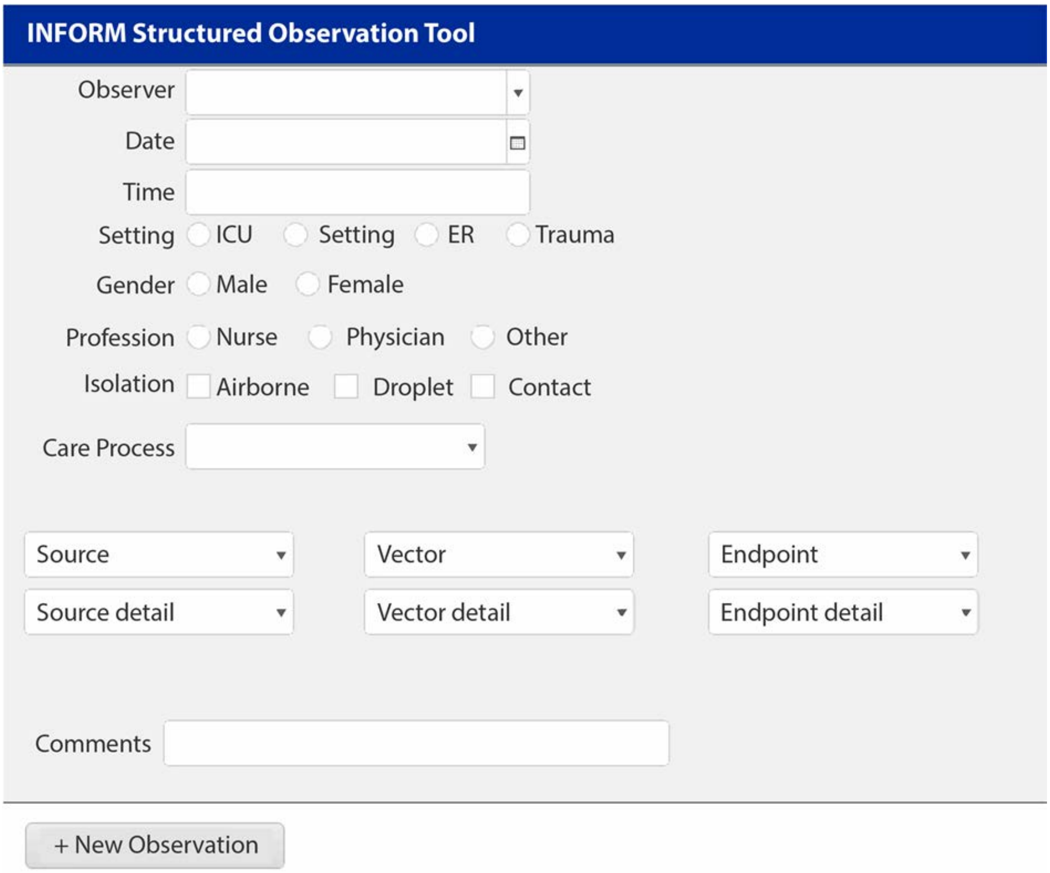

Figure 9: Mobile observation tool interface

Figure 9 Legend: Interface of the mobile observation tool based on the INFORM taxonomy employed for live structured observations. SNF= Swiss national science foundation, ICU = Intensive care unit, WARD = medical ward, ER= emergency room, TRAUMA = trauma unit

RESULTS

Exploratory observations

A total of 129.17 hours of *exploratory observations* resulted in the identification of 292 unique IRM. Identified IRM included moments of potential *direct* contact transmission (potentially infected or colonized HCW to patient) as well as potential *indirect* contact transmission via vectors such as care devices, mobile objects, and HCW clothing and accessories. Following exploratory observations, IRM were systematically coded according to the source, vector and endpoint of pathogens and this formed the basis of the INFORM structured taxonomy (**Figure 8**).

Structured observation taxonomy and mobile observation tool validation

The 3-level taxonomy begins with classification of surfaces (loci) involved in the observed IRM according to source, vector, or endpoint of pathogens (level 1: locus), then assigns each source, vector, and endpoint to a main category (level 2: surface), and specifies the exact nature (level 3: surface detail). Each observed IRM is then represented as a transmission chain composed of three loci (source, vector and endpoint), with each locus having two levels of detail (surface and surface detail). See **Table 2** for examples of archetypal observed and classified IRM for each of the observed vectors.

During the one-month test of the taxonomy using the mobile observation tool (5.5 hours of active patient care), observers one and two detected 78.9% (123) and 75.6% (118) of all observed IRM, respectively. Based on this detection rate, the decision was made to have two observers present for all structured observations to ensure the highest possible sensitivity. For moments identified by both observers during the pilot test, the Cohen’s kappa measure of inter-observer agreement was 0.75, indicating “substantial” agreement between individual observers.(Landis & Koch, 1977)

Structured observations

Following validation of the taxonomy using the mobile observation tool, 53.77 hours of *structured observations* (31.25 hours of active care) were conducted, during which 1,338 IRM were identified. The average density of IRM per active care hour was 42.8 overall, and 34.9, 36.8, and 56.3 in the intensive care, medical, and emergency wards, respectively. We identified 566 unique IRM, which fell into 71 main categories according to level 2 of the structured taxonomy. A comprehensive inventory of observed IRM appears in **Table 3**.

The vectors in the identified IRM included hands (44.54%; n=596), gloves (34.16%; n=457), medical devices (8.59%; n=115), mobile objects (7.62%; n=102), invasive devices (3.96%; n=53), and healthcare worker clothing and accessories (1.12%; n=15). Overall, 25.8% of IRM concerned moments of potential transmission of pathogens to a critical site, described in detail in **Table 3**. Among the 217 moments dealing with medical devices and mobile objects as vectors, 143 (65.90%) concerned moments where disinfection of the device/object had not been observed prior to patient contact. The three most frequently occurring IRM per clinical setting are described in detail in **Table 4**.

DISCUSSION

Hands and gloves continue to be among the most important contributors to transfer of pathogens within the healthcare setting. Nonetheless, we identified moments dealing with other vectors such as medical devices, mobile objects, invasive devices, and HCW clothing and accessories, which may also contribute to patient colonization and/or infection. While previous studies have shown that indications for hand hygiene occur between eight per hour in pediatric wards and 30 per hour in ICUs,(Pittet, Mourouga, & Perneger, 1999b; Hugonnet, Perneger, & Pittet, 2002) we found that IRM occurred with a frequency of 42.8 IRM per active care hour overall and up to 56.3 IRM per active care hour in emergency settings. Similar to opportunities for hand hygiene, the high frequency with which IRM occur suggests that the cumulative risk of negative patient outcomes due to IRM may be significant - although the risk of patient infection or colonization with multi-resistant pathogens at any single IRM may be low. The fact that 25.8% of IRM concerned moments of potential pathogen transfer to critical patient sites further highlights the clinical relevance for infection prevention.

The structured observations in this study were targeted to moments resulting in potential pathogen transfer to the patient, as opposed to movement of pathogens around the larger healthcare environment. Our exploratory observations nonetheless revealed that pathogen transfer from outside to inside the patient zone likely occurred, for example when coming from one patient to silence an alarm on another patient's monitor without hand hygiene, or when transporting mobile objects that come into contact with multiple consecutive patients during clinical rounds. This is consistent with other studies demonstrating that HCW hand hygiene compliance prior to initial contact with the patient or the patient environment is sub-optimal.(Erasmus et al., 2010) This challenges the patient zone concept, which defines the patient and his/her immediate surroundings (e.g. bed rails, bedside table, and medical equipment) and frequently touched surfaces (e.g. monitors, knobs and buttons) as the "patient zone" and assumes that surfaces within the patient zone are colonized by patient flora.(Sax et al., 2007) When disinfection is omitted prior to contact with the patient or patient environment, (Erasmus et al., 2010) it is likely that pathogens from the healthcare environment are introduced to these surfaces. Such ambiguity is a major challenge to safe behavior.(Sax & Clack, 2015) For this reason, during observations we considered that environmental surfaces could potentially harbor pathogenic bacteria regardless of their location inside or outside of the patient zone.

Similarly, our findings are consistent with multiple systematic reviews which have demonstrated that the frequent movement of healthcare equipment(Schabrun & Chipchase, 2006) and care items(Livshiz-Riven et al., 2015) between patients, together with sub-optimal or missing disinfection of such items, result in transfer of pathogens between patients. Potential contamination or missing disinfection (classified as Source = "unknown status", Source detail = "no disinfection observed") of medical devices and mobile objects accounted for 16.2% of observed IRM in this study (**Table 3**).

The transmission-based observational approach employed in this study, which sought to identify all behaviors potentially resulting in transmission pathogen, differs from traditional rule-based observations that measure compliance with existing local or national guidelines. Observations using the INFORM taxonomy could hence be employed in additional settings, regardless of local guidelines, to identify the most frequently occurring IRM and to establish local infection prevention priorities.

The results of this study should be interpreted in light of some limitations. It is possible that being observed influenced HCW behavior during this study.(Parsons, 1974) It is unlikely however that this resulted in systematic bias, because HCW were not aware of exactly what was being observed. Observations were limited to contact transmission (i.e., the most common mode of transmission(Siegel et al., 2007)), and did not consider airborne and droplet transmission. Further, our observations did not consider other behaviors that may also impact infectious risks, such as those interfering with the patient's defense system against infectious risks (such as immune status, skin integrity, cough reflex, etc.) because the associated HCW behavior rarely occurs at the bedside. Moreover, these observations were conducted in one university hospital located in a high-income setting, limiting the generalizability of our findings. Further exploration of the nature and frequency of IRM using the INFORM structured observational taxonomy is therefore warranted to assess local priorities for infection prevention efforts in additional care settings. Finally, the risk of transmission during each type of IRM remains unknown. We aimed to bridge this gap through a modified Delphi survey with an international panel of experts in infectious diseases, infection prevention and control, and microbiology, in which experts rated the likelihood of infectious outcomes (e.g. colonization, infection) following archetypical IRM (Clack, Passerini, Manser, & Sax, 2018a).

Despite these limitations, the combination of methods employed in this study was well suited to identify a wide range of potential IRM and to systematically observe their frequency and nature in multiple healthcare settings. The resulting mobile observation tool featuring the INFORM taxonomy of source, vector, and endpoint of pathogens was useful for the systematic documentation and categorization of IRM. Further observations based on the INFORM taxonomy may prove useful in other settings to identify the most frequently occurring IRM, to establish educational content, and to prioritize targeted infection prevention strategies.

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Table 2: Example coding of archetypal infectious risk moments using the INFORM structured taxonomy

Gloves: A healthcare worker wearing gloves removes and discards the dressing from a patient's open wound, his gloves coming into contact with the open wound, then, without changing gloves, touches the insertion site of the same patient's urinary catheter.

Level 1: Locus	Source	Vector	Endpoint
Level 2: Surface	Patient critical site	Gloves	Critical site
Level 3: Surface detail	Open wound	Non-sterile gloves	Urinary catheter

Healthcare worker: While adjusting the electrocardiography suction nodes to a patient's upper limbs, a healthcare worker leans over the patient, his badge touching the intact skin of the patient's arm.

Level 1: Locus	Source	Vector	Endpoint
Level 2: Surface	Unknown status	Healthcare worker	Non-critical site
Level 3: Surface detail	No disinfection observed	Badge	Upper limbs

Invasive device: A healthcare worker inserts an arterial catheter without having disinfected the skin of the insertion site.

Level 1: Locus	Source	Vector	Endpoint
Level 2: Surface	Patient intact skin	Invasive device	Critical site
Level 3: Surface detail	Contaminated skin	Arterial catheter tip	Bloodstream

Medical device: A healthcare worker carries a stethoscope around her neck, the chest piece coming into contact with her own skin, then, without disinfection, she uses the stethoscope to auscultate the patient.

Level 1: Locus	Source	Vector	Endpoint
Level 2: Surface	Healthcare worker	Medical device	Non-critical site
Level 3: Surface detail	Body	Stethoscope	Trunk

Mobile object: Medical-grade adhesive tape is attached to bedrails prior to being used to secure the gauze of a wound dressing onto the patient's skin.

Level 1: Locus	Source	Vector	Endpoint
Level 2: Surface	Environment	Mobile object	Non-critical site
Level 3: Surface detail	Patient bed	Medical tape	Wound dressing

Table 3: Inventory and observed frequency of all infectious risk moments per care setting by A) critical site and B) non-critical site

A) Infectious risk moments involving transfer to critical patient sites

Source		Pathway		Endpoint	all	ICU	MED	ER
Environment	→	Gloves	→	Critical site	99	36	35	14
Medical device	→	Gloves	→	Critical site	46	28	3	1
Mobile object	→	Gloves	→	Critical site	20	14	3	2
Patient intact skin	→	Gloves	→	Critical site	17	8	3	5
Healthcare worker	→	Gloves	→	Critical site	15	11	1	0
Invasive device	→	Gloves	→	Critical site	1	0	0	0
Other patient	→	Gloves	→	Critical site	1	1	0	0
Environment	→	Hands	→	Critical site	41	17	12	4
Medical device	→	Hands	→	Critical site	24	12	3	1
Healthcare worker	→	Hands	→	Critical site	5	2	1	0
Mobile object	→	Hands	→	Critical site	4	1	3	0
Patient intact skin	→	Hands	→	Critical site	2	0	0	0
Invasive device	→	Hands	→	Critical site	1	0	1	0
Gloves	→	Invasive device	→	Critical site	19	14	2	0
Patient intact skin	→	Invasive device	→	Critical site	13	4	1	8
Environment	→	Invasive device	→	Critical site	12	8	1	1
Healthcare worker	→	Invasive device	→	Critical site	4	1	0	0
Hands	→	Invasive device	→	Critical site	3	3	0	0
Patient critical site	→	Invasive device	→	Critical site	1	1	0	0
Gloves	→	Medical device	→	Critical site	3	0	1	2
Hands	→	Medical device	→	Critical site	1	1	0	0
Unknown status	→	Medical device	→	Critical site	1	0	1	0
Environment	→	Mobile object	→	Critical site	4	1	1	0
Patient critical site	→	Mobile object	→	Critical site	4	0	0	0
Gloves	→	Mobile object	→	Critical site	1	0	1	1
Hands	→	Mobile object	→	Critical site	1	0	0	2
Patient intact skin	→	Mobile object	→	Critical site	1	1	0	0
Unknown status	→	Mobile object	→	Critical site	1	2	2	0

B) Infectious risk moments involving transfer to non-critical patient sites

Source		Pathway		Endpoint	all	ICU	MED	ER
Environment	→	Gloves	→	Non-critical site	97	26	24	27
Medical device	→	Gloves	→	Non-critical site	61	9	3	14

Source		Pathway		Endpoint	all	ICU	MED	ER
Mobile object	→	Gloves	→	Non-critical site	45	8	10	10
Patient intact skin	→	Gloves	→	Non-critical site	17	7	1	4
Healthcare worker	→	Gloves	→	Non-critical site	15	4	1	4
Patient critical site	→	Gloves	→	Non-critical site	9	1	4	3
Invasive device	→	Gloves	→	Non-critical site	1	1	0	0
Environment	→	Hands	→	Non-critical site	229	34	91	90
Mobile object	→	Hands	→	Non-critical site	92	16	33	38
Medical device	→	Hands	→	Non-critical site	77	21	22	24
Healthcare worker	→	Hands	→	Non-critical site	68	9	40	13
Patient intact skin	→	Hands	→	Non-critical site	17	6	4	5
Other patient	→	Hands	→	Non-critical site	2	0	2	0
Exterior	→	Hands	→	Non-critical site	1	0	1	0
Patient critical site	→	Hands	→	Non-critical site	1	1	0	0
Unknown status	→	Hands	→	Non-critical site	1	0	1	0
Unknown status	→	HCW	→	Non-critical site	13	5	1	3
Patient intact skin	→	HCW	→	Non-critical site	2	2	0	0
Unknown status	→	Medical device	→	Non-critical site	81	0	0	1
Healthcare worker	→	Medical device	→	Non-critical site	13	2	0	1
Hands	→	Medical device	→	Non-critical site	3	0	0	1
Gloves	→	Medical device	→	Non-critical site	1	2	0	1
Patient intact skin	→	Medical device	→	Non-critical site	1	0	1	0
Unknown status	→	Mobile object	→	Non-critical site	43	1	0	0
Environment	→	Mobile object	→	Non-critical site	17	1	2	0
Healthcare worker	→	Mobile object	→	Non-critical site	6	0	0	1
Patient intact skin	→	Mobile object	→	Non-critical site	4	0	0	0
Gloves	→	Mobile object	→	Non-critical site	2	1	0	0
Medical device	→	Mobile object	→	Non-critical site	2	0	6	0
Patient critical site	→	Mobile object	→	Non-critical site	1	4	0	0
Environment	→	Gloves	→	Patient bed	7	0	0	5
Medical device	→	Gloves	→	Patient bed	5	0	0	0
Healthcare worker	→	Gloves	→	Patient bed	1	0	0	0
Environment	→	Hands	→	Patient bed	18	3	8	7
Healthcare worker	→	Hands	→	Patient bed	5	1	2	0
Medical device	→	Hands	→	Patient bed	5	3	0	2
Mobile object	→	Hands	→	Patient bed	3	0	2	1
Environment	→	Invasive device	→	Patient bed	1	1	0	0
Unknown status	→	Medical device	→	Patient bed	7	9	26	42

Source		Pathway		Endpoint	all	ICU	MED	ER
Healthcare worker	→	Medical device	→	Patient bed	1	2	1	9
Unknown status	→	Mobile object	→	Patient bed	10	6	12	18
Environment	→	Mobile object	→	Patient bed	5	5	5	0

Table 3 Legend: ICU=Intensive care unit, MED=General medical ward, ER=Emergency ward, HCW=Healthcare worker

Table 4: Three most frequently occurring infectious risk moments per clinical setting

Setting	Source	Vector	Endpoint	Frequency°	Density*
Intensive care unit	**Environment**	**Gloves**	**Critical site**	**36**	**3.51**
	Example: A healthcare worker wearing gloves touches the trolley next to the patient's bed then, without changing gloves, verifies the patient's mechanical ventilator, the gloves coming into contact with the patient's mouth.				
	Environment	**Hands**	**Non-critical Site**	**34**	**3.31**
	Example: A healthcare worker handles the paper charts (medical records) of a sedated patient then, without hand hygiene, proceeds to touch the intact skin on the patients upper limbs.				
	Medical devices	**Gloves**	**Critical site**	**28**	**2.73**
	Example: A healthcare worker wearing gloves manipulates the interface of an infusion pump to programme the delivery rate then, without changing gloves, verifies the insertion site of a peripheral venous catheter.				
Medical ward	**Environment**	**Hands**	**Non-critical Site**	**91**	**8.78**
	Example: After touching the environment outside of the patient's room, a healthcare worker enters a patient's room and, without doing hand hygiene, shakes the patient's hand.				
	Healthcare worker	**Hands**	**Non-critical Site**	**40**	**3.86**
	Example: A healthcare worker stands with arms crossed, his hands coming into contact with his white professional clothing then, without doing hand hygiene, proceeds to examine the patient, touching intact skin on the patient's stomach.				
	Environment	**Gloves**	**Critical site**	**35**	**3.38**
	Example: While changing a wound dressing, a healthcare worker wearing gloves touches the surface and drawers of the trolley containing dressing materials, then with the same gloves makes contact with the patient's open wound.				
Emergency ward	**Environment**	**Hands**	**Non-critical Site**	**104**	**9.7**
	Example: After touching the environment outside of the patient's room, a healthcare worker enters a patient's room and, without doing hand hygiene, shakes the patient's hand.				
	Medical devices	**Gloves**	**Non-critical Site**	**49**	**4.62**
	Example: A healthcare worker wearing gloves touches the electronic interface of an electrocardiography machine (ECG), whose disinfection had not been observed prior to using, then with the same gloves touches the patient's intact skin while applying the ECG nodes to the patient.				
	Environment	**Gloves**	**Non.-critical site**	**47**	**4.43**
	Example: A healthcare worker wearing gloves pulls closed the curtains that divide patient rooms then wearing the same gloves touches the patient's upper limbs.				

Table 4 Legend: This table presents the three most frequently occurring main categories of infectious risk moments (IRM) based on level 2 of the structured taxonomy; ° Frequency = number of times the IRM was observed in the indicated setting; *Density = frequency / hours of active patient care in the indicated setting

3.2. STUDY 3: "FIRST-PERSON VIEW" OF PATHOGEN TRANSMISSION AND HAND HYGIENE - USE OF A NEW HEAD-MOUNTED VIDEO CAPTURE AND CODING TOOL.

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A similar version of this paper has been published:

Clack, L.*, Scotoni, M.*, Wolfensberger, A., & Sax, H. (2017). "First-person view" of pathogen transmission and hand hygiene - use of a new head-mounted video capture and coding tool. *Antimicrob Resist Infect Control, 6,* 108. doi:10.1186/s13756-017-0267-z

* Equal contributions as first authors

ABSTRACT

Background

Healthcare workers' hands are the foremost means of pathogen transmission in healthcare, but detailed hand trajectories have been insufficiently researched so far. We developed and applied a new method to systematically document hand-to-surface exposures (HSE) to delineate true hand transmission pathways in real-life healthcare settings.

Methods

A head-mounted camera and commercial coding software were used to capture ten active care episodes by eight nurses and two physicians and code HSE type and duration using a hierarchical coding scheme. We identified HSE sequences of particular relevance to infectious risks for patients based on the WHO 'Five Moments for Hand Hygiene'. The study took place in a trauma intensive care unit in a 900-bed university hospital in Switzerland.

Results

Overall, the ten videos totalled 296.5 minutes and featured eight nurses and two physicians. A total of 4,222 HSE were identified (1 HSE every 4.2 seconds), which concerned bare (79%) and gloved (21%) hands. The HSE inside the patient zone (n=1775; 42%) included mobile objects (33%), immobile surfaces (5%), and patient intact skin (4%), while HSE outside the patient zone (n=1953; 46%) included HCW's own body (10%), mobile objects (28%), and immobile surfaces (8%). A further 494 (12%) events involved patient critical sites. Sequential analysis revealed 291 HSE transitions from outside to inside patient zone, i.e. "colonization events", and 217 from any surface to critical sites, i.e. "infection events". Hand hygiene occurred 97 times, 14 (5% adherence) times at colonization events and three (1% adherence) times at infection events. On average, hand rubbing lasted 13±9 seconds.

Conclusions

The abundance of HSE underscores the central role of hands in the spread of potential pathogens while hand hygiene occurred rarely at potential colonization and infection events. Our approach produced a valid video and coding instrument for in-depth analysis of hand trajectories during active patient care that may help to design more efficient prevention schemes.

INTRODUCTION

Healthcare-associated infections, including surgical site infections, ventilator-associated pneumonia, urinary tract infections, and catheter-associated bloodstream infections, prolong length of hospital stay and increase cost, morbidity and mortality (Harbarth et al., 2003; Graves et al., 2007; Umscheid et al., 2011). Additionally, antibiotic resistance is emerging worldwide as a serious health threat (*Antimicrobial resistance*, 2014).

Transmission of potential pathogens between patients occurs primarily via healthcare worker (HCW) hands when hand hygiene (HH) is omitted at critical moments (Boyce, Pittet, Committee, & Force, 2002; Pittet et al., 2006b). Such hand-to-surface exposures (HSE) occur frequently (Clack et al., 2014), resulting each time in a bi-directional exchange of microorganisms between the hand and the touched surface (Pittet et al., 2006b). In consequence, hands transport microorganisms sequentially between surfaces (Pittet et al., 2006b). Depending on the nature of the microorganisms and of the receiving surface, this can result in patient harm. If microorganisms feature antibiotic resistance, their transmission to a patient can result in prolonged carriage. If the microorganisms are virulent and the receiver surface is a skin lesion or an invasive device such as a central venous line, the transmission may result in healthcare-associated infection.

Several studies show that infectious microorganisms can survive on human skin long enough to be cross-transmitted and that hand hygiene using alcohol-based handrub is an effective way to decrease this transmission (Thomas, Boquete-Suter, Koch, Pittet, & Kaiser, 2014; L'Huillier et al., 2015). With the WHO “My five moments for hand hygiene”, a user-centred concept based on education, training, monitoring and reporting of hand hygiene has been introduced with the goal to bridge the gap between scientific evidence and daily healthcare practice (Sax et al., 2007). Yet, HCWs still fail to consistently apply hand hygiene. The lack of awareness regarding what people touch during their routine work may play an important role in this failure to adhere to established rules (Sax & Clack, 2015). Today’s gold standard to monitor HH performance consists of direct observation of healthcare workers by trained observers during patient care (Boyce et al., 2002; Boyce, 2008; Braun, Kusek, & Larson, 2009; Organization., 2009). This method may not capture every HSE during fast-paced care and thus, underestimates the true risk of pathogen transmission (Sax et al., 2009; Clack et al., 2014). On the other hand, automated electronic hand hygiene monitoring systems still fall short of detecting all hand hygiene opportunities (Ward et al., 2014).

To better understand the nature of microbial hand-transmission in a real-life intensive healthcare setting, we built and pilot-tested a new observation and coding system that would consistently capture every HSE, and thus allow to study true transmission risks via HCWs' hands.

METHODS

Setting up and offsite-testing of the system

We opted for a mobile, head-mounted action camera (GoPro® Hero 4 Black edition, GoPro Inc., San Mateo, CA) worn by HCW during patient care. The camera was positioned on the forehead of the HCW by means of a head-strap and was oriented facing slightly downwards. With the help of an iPad mini (Apple, Cupertino, CA) the researcher could control the optimal orientation of the camera through a Wi-Fi connection. The camera was oriented to keep the participant's hands in its visual field. In a first round, we tested and adjusted the camera in the medical high-fidelity simulator of our institution. After resolving all technical issues, we proceeded to videotape real-life care activity in three intensive care units (ICUs) specialized in trauma, cardiology, and visceral surgery at the University Hospital Zurich (USZ), Switzerland. The USZ is a 900-bed university-affiliated tertiary care centre with a well-established infection prevention and control (IPC) group, weekly IPC rounds, and a designated IPC nurse consultant for each hospital ward.

Participants and onsite-use of the system

A convenience sample of 10 participants was recruited among ICU nurses and physicians. Each participant wore the head-mounted camera during his/her morning shift for about 70 minutes. Morning shifts were chosen purposefully to guarantee that patient care activity took place. Subsequently, HCW continued their care activity without further interruptions by the researcher, who left the area.

Video coding

The videos were exported from the camera and stored on a secured server. Episodes of ~30 minutes direct patient care were purposefully selected from each of the 10 videos for further processing. Within each of these video episodes, the occurrence, duration, and type of every HSE was systematically coded by a trained coder (MS) and supervised by a second person (LC) using the behavioural observation software INTERACT® (Mangold international, Arnstorf, Germany) together with a structured, hierarchical coding system (**Figure 10**).

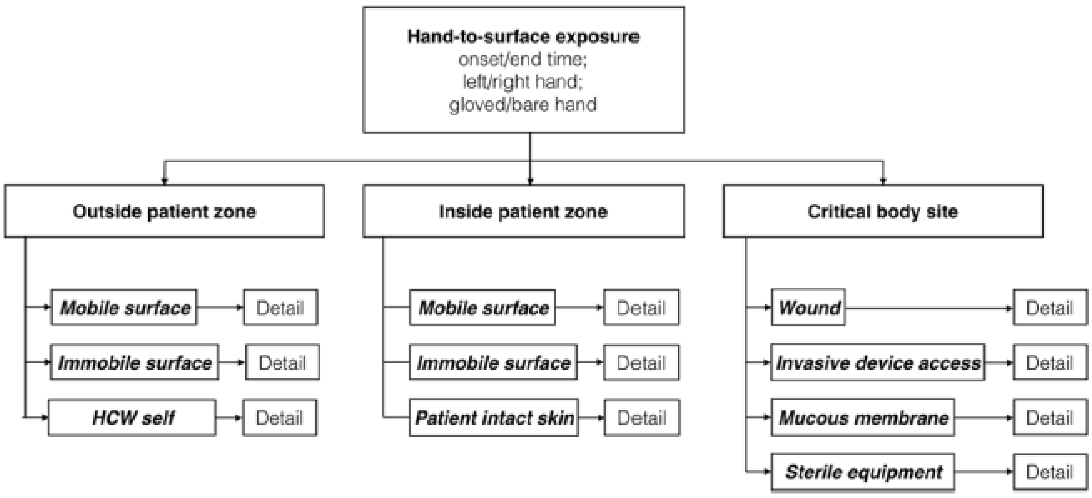

Figure 10: Hierarchical coding system

Figure 10 Legend: HCW self, healthcare workers touching themselves; one hand touching the other hand of the same HCW was not considered

The observation and coding system aimed to capture the duration and nature of all HSE, defined as contact between the observed healthcare worker's hand and any other surface. The hierarchical coding system consisted of 4 levels, of which the first two indicate the nature of the hand (gloved vs. bare and right vs. left), and the latter two indicate the nature of the surface (location relative to patient zone and type of surface) involved in the hand-to-surface exposure (**Figure 10**). In line with the WHO patient zone concept (Sax et al., 2007) and observation method (Sax et al., 2009) the third coding level distinguished between surfaces "inside patient zone", "outside patient zone", and "critical sites". "Inside patient zone" was defined as the patient him-/herself and all items in the immediate environment likely to be colonized with patient flora (Sax et al., 2007). The "outside patient zone" contained other patients with their respective zones, the HCW's own body and professional apparel ("HCW Self"), and all the other areas and surfaces outside the patient zone (Sax et al., 2007). "Critical sites" included clean sites such as medical devices or patient's body parts that have to be protected against microbial colonization in order to avoid infections (Sax et al., 2007). Hand hygiene actions were registered as specific events and coded as either "hand washing" or "hand disinfection" with alcohol-based handrub. Patient zones were established a-priori for each ICU setting to ensure accurate and consistent coding (**Figure 11**).

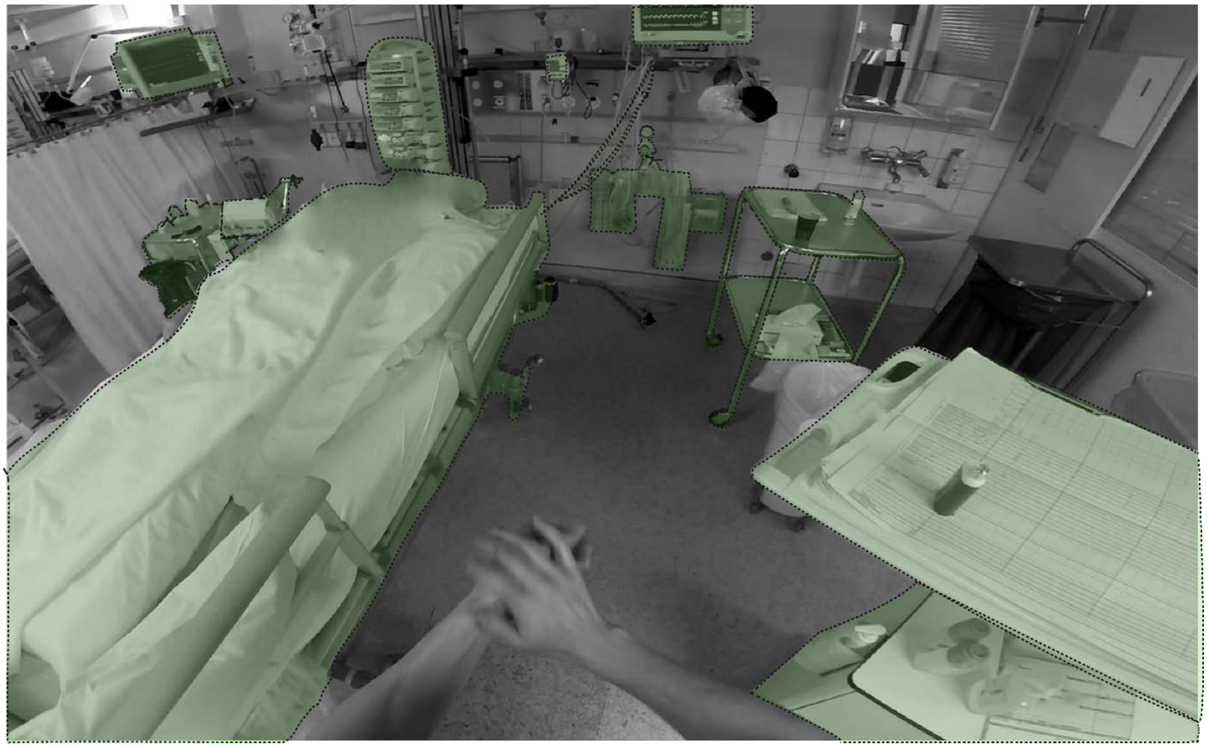

Figure 11: Visual field of head-mounted action camera and color-coded patient zone

Figure 11 Legend: This screenshot demonstrates the first-person view recorded from the head camera. Objects and surfaces belonging to the patient zone are colored with a green overlay and dotted outline

Data analysis

To assess the utility of the observation and coding system, we performed a descriptive analysis of frequency and duration of HSE. Coded event data were exported as comma separate values (.cvs) files, merged and edited in Excel (Microsoft, Redmond, WA) and analysed in STATA special edition 12.0 (StataCorp, College Station, TX). Sequential analysis was additionally conducted to identify HSE sequences of particular relevance to infectious risks, as informed by the WHO ‘Five Moments for Hand Hygiene’(Sax et al., 2007). We defined sequences of touching a surface outside the patient zone followed by touching any surface inside a patient zone as a ‘*colonization event*’ and a sequence of touching any surface, except a critical site, followed by touching a critical site as an ‘*infection event’* (**Table 5**)**.** A *colonization event* would correspond to a modified WHO “Five

Moments" concept's Moment 1 "Before touching a patient" but include touching any surface inside the patient zone and not only the patient. This modification of Moment 1 was made to capture more precisely colonization risk of the patient by hospital flora that is brought into the immediate vicinity of the patient and from there to the patient. An *infection event* would correspond to WHO "Five Moments" concept's Moment 2 "Before clean/aseptic procedure". According to Sax et al., "Critical sites for infectious risks" included breaks in the patient's intact skin such as wounds and catheter insertion sites, any patient mucous membrane, invasive devices in-situ if the lumen was accessed such as vascular or urinary catheters, and semi-critical or critical medical devices ready to be used on the patient (Sax et al., 2007).

RESULTS

The 10 active care video sequences totalled 296.5 minutes and featured eight nurses of whom seven were female and two physicians of whom one was female, all right handed. Overall, 4222 HSE occurred, translating in an overall density of 14.2 HSE per minute or one HSE every 4.2 seconds. Exemplarily, **Figure 12** demonstrates the coding timeline of all HSE and hand hygiene actions in the first three minutes of video #7. Details on the frequency and nature of HSE and hand hygiene actions overall and per each video sequence appear in **Table 5**.

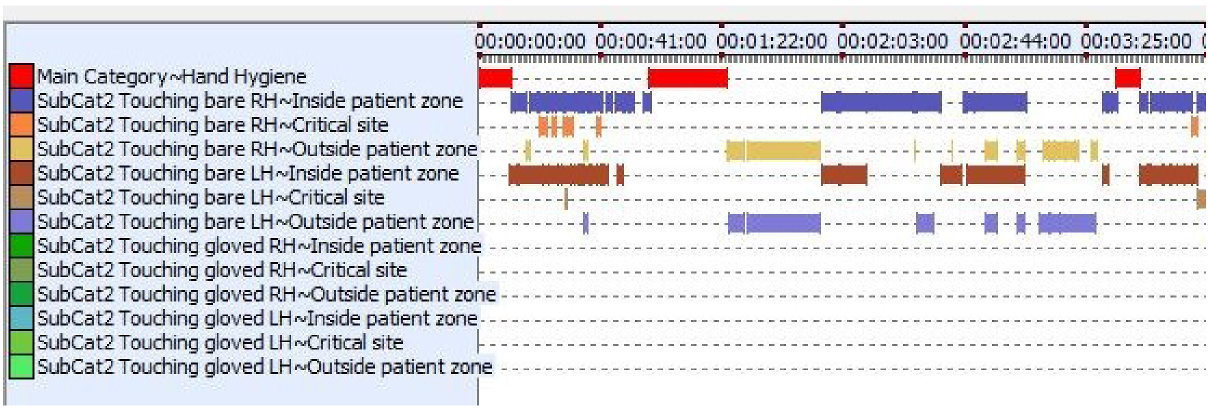

Figure 12 Example timeline of coded video #7

Figure 12 Legend: An excerpt of the coding timeline from video #7. X-axis: time from 0:00–3:25 minutes. Y-Axis from top to bottom: Hand hygiene action, hand-to-surface exposure (HSE) patient zone bare right hand inside, HSE to critical site with bare right hand, HSE outside patient zone with bare right hand, HSE inside patient zone with bare left hand, HSE at critical site bare left hand, HSE outside patient zone with bare left hand, HSE inside patient zone with gloved right hand, HSE to critical site with gloved right hand, HSE outside patient zone with gloved right hand, HSE inside patient zone with gloved left hand, HSE at critical site with gloved left hand, HSE outside patient zone with gloved left hand.

The mean and median duration of the 97 observed hand hygiene actions were 12.9 (SD, 8.7) and 11 (range, 2-48) seconds, respectively. Patient *colonization events* occurred overall 291 times, 139 for the left and 152 for the right hand. Patient *infection events* were observed overall 217 times, 103 for the left and 114 for the right hand. Importantly, 117 (61%) of *colonization events* and seven (2.3%) *infection events* occurred after HCWs touching their own body. HCWs touched themselves 439 times (10% of all HSE), including their clothes 165 (38%), personal protective equipment 21 (5%), their face 24 (6%), and remaining bare skin or hair 229 (52%) times; 13 (3%) times with gloved hands.

Hand hygiene occurred prior to 14 of the 191 *colonization events* and three of the 217 *infection events*, resulting in a hand hygiene 'adherence' of 5% and 1%, respectively.

DISCUSSION

This unique video observation and coding approach, that considers each single HSE by both HCW hands, revealed a surprising reality of transmission opportunities during real-world intensive care. The overall density of 14.2 HSE per minute with which HCWs' hands touched surfaces during active patient care is high, suggesting that hands acquire and deposit – and thus likely transmit – potentially harmful microorganisms every four seconds onto patients and surfaces in the care environment. We identified sequences of particular interest for infection prevention, such as patient zone entries and transitions to critical sites, which each occurred roughly every two minutes of active patient care in an ICU. Hand hygiene was performed on average 19.6 times per hour, which equals one hand hygiene action every three minutes. It is not surprising that participants only sustained hand rubbing for a median of 11 seconds against the recommended 20-30 seconds (*WHO guidelines on hand hygiene in health care*, 2009). In fact, if meeting the recommended duration for hand rubbing, almost one fifth of active patient care time would have been spent on this activity. Recent data indicating that 15 seconds might suffice are comforting in this respect (Pires, Soule, Bellissimo-Rodrigues, Gayet-Ageron, & Pittet, 2017).

The approach used in this study is in line with a human factors task analysis, whose underlying principle is to break down a task to study its individual elements (Stanton, 2006). In doing so, we aim to understand the factors that influence the way work is being done and, ultimately, what can be done to improve it (Clack & Sax, 2017a, 2017b). In doing so, the moments we report here are more frequent than those usually reported in direct hand hygiene observation studies. For example, tasks such as a dressing change are typically seen as constituting one single hand hygiene opportunity with an indication ‘Before clean/aseptic procedure’ before the task and ‘After body fluid exposure risk’ at the end of the task (Sax et al., 2007). In the current approach, each care task is split into multiple HSEs, taking into account both mobile objects and the HCWs own body, each scrutinized for potential hand contamination and transmission. Furthermore, traditional hand hygiene models are based on the assumption that surfaces within the patient zone are colonised primarily with the patient’s own flora. Our results (Sax & Clack, 2015), however, demonstrate that frequent transitions of hands into the patient zone without hand hygiene may lead to contamination of the patient zone with foreign microorganisms. Such lapses lead to an unsafe system state, which creates ambiguity (Gurses et al., 2008b) and may result in unintentional patient harm.

Our approach revealed further noteworthy realities. We considered the HCW’s own body as an ‘Outside patient zone’ surface. More than half of all HSE sequences (61%) from the “outside” to the “inside” patient zone were due to ‘self-contact’. Current hand hygiene guidelines often fail to address HCW self-contact as an indication for hand hygiene (*WHO guidelines on hand hygiene in health care*, 2009). Hence, such HSE are usually ignored by observers. Second, much variation exists in whether HCWs perceive their professional apparel as a potential source of bacteria, leading to variations in hand hygiene (Whitby et al., 2007). Additionally, as described by Sax & Clack, relying on automatic, unconscious behaviours fuelled by “mental models” for routine tasks is inherent to the nature of human beings, allowing mental resources to be spared for more complex tasks (Sax & Clack, 2015). This suggests that people often are unaware of what exactly their hands do while they are focused on the main task goal (Sax & Clack, 2015). The average of 1.48 exposures per minute to a HCW’s own body is consistent with previous findings (Nicas & Best, 2008; Kwok, Gralton, & McLaws, 2015). However, with only 4.87 exposures per hour to “HCW Face”, our results differed from studies who found that face contact occurred up to 15-23 times per hour among students during 2-hour lectures (Kwok et al., 2015) or during office-type work (Nicas & Best, 2008). Finally, glove use was frequent, representing one fifth of all HSE. Gloves represent mobile surfaces that transport microorganisms like bare hands. Further research could explore the nature of HSE during glove use to inform best practice for glove indications.

The “first-person view” of a head-mounted action camera provides the advantage of an unobstructed view of both hands and the surfaces they touch following the healthcare worker even when leaving the immediate care area, neither of which can be guaranteed with a fixed-position camera. From anecdotal reports by the participants, their awareness of wearing a camera and their activity being registered waned quickly, suggesting a minor Hawthorne effect, yet this remains to be studied systematically. Contrary to concerns about video recording in acute care settings, we found that once healthcare workers, patients, and their relatives were informed of the study goals, objections to filming were rare. Video observation of hand hygiene behaviour has been used before (Swoboda, Earsing, Strauss, Lane, & Lipsett, 2004; Sahud et al., 2010; Armellino et al., 2012; Palmore & Henderson, 2012) but never from a first-person view and never to record HSEs.

Our approach has limitations. The analysis is limited to a small sample of healthcare workers in three ICUs and in consequence not representative for care in general. We do not expect, however, the main findings of frequent HSE to be categorically different. Furthermore, while the sequential analysis we report here considers only pairs of two consecutive HSE leading up to “colonisation” or “infection” events, it is important to recognize that HSE occur in long sequential chains. The exact benefit of hand hygiene at any of these moments has not been considered in our current calculation, nor in the WHO ‘Five moments’ concept. In this line of thought, our approach might serve as a basis for more advanced future transmission risk modelling. Our definition of a *colonization event* deviated from ‘Moment 1’ of the WHO hand hygiene concept by including any object within the patient zone, not only the patient. We did this intentionally to identify the transmission trajectories most likely leading to contamination of high-touch surfaces near the patient and ultimately, the patient. On a technical note, the specific software is expensive and its use requires expertise. Video coding is more time-consuming than live observation. Hence, before introducing this instrument into day-to-day practice beyond research, simplification and automation is a desirable next development step. Finally, the videos were coded by a single coder (MS) and supervised by a second person (LC) due to feasibility. The possibility to pause and rewind the video likely minimized the risk of miscoding.

In conclusion, our approach produced a valid video and coding instrument for analysis of detailed HSE trajectories. Using a head-mounted action camera and a comprehensive coding system, we could show for the first time in a fast-paced, real clinical setting how frequently healthcare workers’ hands touch surfaces, corroborating the fast spread of microorganisms in healthcare settings. Further development and use of this method may contribute to the design of more efficient preventive strategies.

CONCLUSIONS

Using a new head-mounted action camera and a systematic coding tool, we could show for the first time how healthcare workers' hands touch surfaces in a real-world clinical setting. This human factors approach to task analysis demonstrated the hand trajectories via which microorganisms can spread in healthcare and revealed that hand hygiene adherence is lower than usually reported by traditional on-site observations. This new instrument may assist in designing more efficient preventive strategies on an individual and systems level.

DECLARATIONS

Ethics approval and consent to participate

Due to the quality improvement scope of this study, the Ethics Review Board of the Canton of Zurich formally waived the need for ethics review. Signed consent was sought of patients or their relatives in accordance with the University Hospital Zurich regulations for videotaping and photography. Participants gave their oral consent after an in-depth explanation of the study goals and proceedings and could opt out at any time. Data were rendered anonymous in the coding database.

Consent for publication

Not applicable.

Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the design, conduct of the study, the analysis of the data, and the writing of the manuscript.

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We would like to warmly thank the healthcare workers and patients who had the courage and kindness to contribute to this research.

Table 5: Hand-to-surface exposures and hand hygiene actions

Video	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	Overall
ICU specialty	Trauma	Trauma	Trauma	Trauma	Cardio-surgery	Cardio-surgery	Cardio-surgery	General surgery	Cardio-surgery	General surgery	
Length of coded care sequence; min:sec	34:50	34:50	34:50	36:20	31:17	32:38	33:31	16:39	32:19	16:32	296:30
Gender	M	F	F	F	F	F	M	M	F	F	
Profession	N	N	N	N	N	N	N	P	N	P	
HSE; n	494	472	314	495	474	671	553	176	526	47	4222
HSE density; n/min	14,2	13,6	9,0	13,6	15,2	20,6	16,5	10,6	16,3	2,8	14,2
Mean HSE duration (SD); sec	8.9 (16.0)	6.8 (10.0)	11.7 (17.0)	8.1 (18.5)	7.0 (14.9)	5.3 (10.5)	5.6 (11.8)	11.7 (15.1)	6.8 (10.7)	11.8 (26.5)	7.44 (14.1)
Hand											
Right hand (%)	273 (55.3)	254 (53.8)	173 (55.1)	277 (56.0)	250 (52.7)	358 (53.4)	304 (55.0)	93 (52.8)	292 (55.5)	25 (53.2)	2299 (54.5)
Left hand (%)	221 (44.7)	218 (46.2)	141 (44.9)	218 (44.0)	224 (47.3)	313 (46.7)	249 (45.0)	83 (47.2)	234 (44.5)	22 (46.8)	1923 (45.6)
Gloves worn during HSE											
No (%)	355 (71.9)	420 (89.0)	221 (70.4)	214 (43.2)	406 (85.7)	671 (100)	334 (60.4)	176 (100)	474 (90.1)	47 (100)	3318 (78.6)
Yes (%)	139 (28.1)	52 (11.0)	93 (29.6)	281 (56.78)	68 (14.4)	0	291 (39.6)	0	52 (9.9)	0	904 (21.4)
Any surface inside patient zone (% of all HSE)	289 (58.5)	222 (47.0)	196 (62.4)	133 (26.9)	131 (27.6)	134 (20.0)	225 (40.7)	122 (69.3)	278 (52.85)	45 (95.7)	1775 (42.0)
Patient intact skin (% of HSE inside patient zone)	12 (4.2)	30 (13.5)	12 (6.1)	13 (9.8)	0	15 (11.2)	45 (20.0)	8 (6.6)	29 (10.4)	14 (31.1)	178 (10.0)
Mobile object inside patient zone (% of HSE inside patient zone)	241 (83.4)	163 (73.4)	130 (66.3)	112 (84.2)	117 (89.3)	80 (59.7)	168 (74.7)	109 (89.3)	234 (84.2)	29 (64.4)	1383 (77.9)
Immobile surface inside patient zone (% of HSE inside patient zone)	36 (12.5)	29 (13.1)	54 (27.6)	8 (60.2)	14 (10.7)	39,829.1)	12 (5.3)	5 (4.1)	15 (5.4)	2 (4.4)	214 (12.1)
Any surface outside patient zone (% of all HSE)	148 (30.0)	220 (46.6)	89 (28.3)	350 (70.7)	322 (67.9)	506 (75.4)	115 (20.8)	53 (30.1)	148 (28.1)	2 (4.3)	1953 (46.3)
HCW own body (outside patient zone) (% of HSE outside patient zone)	7 (4.7)	36 (16.4)	25 (28.1)	47 (13.4)	60 (18.6)	107 (21.2)	79 (68.7)	50 (94.3)	28 (18.9)	0	439 (22.5)
Mobile object outside patient zone (% of HSE outside patient zone)	114 (77.0)	160 (72.7)	49 (55.1)	235 (67.1)	175 (54.4)	346 (68.4)	18 (15.7)	3 (5.7)	92 (62.2)	2 (100)	1194 (61.1)
Immobile surface outside patient zone (% of HSE outside patient zone)	27 (18.2)	24 (10.9)	15 (16.9)	68 (19.4)	87 (27.0)	53 (10.5)	18 (15.7)	0	28 (18.9)	0	320 (16.4)
Any critical site (inside patient zone) (% of all HSE)	57 (11.5)	30 (6.4)	29 (9.2)	12 (2.4)	21 (4.4)	31 (4.6)	213 (38.5)	1 (0.6)	100 (19.0)	0	494 (11.7)
Sterile equipment (% of HSE at critical site)	1 (1.8)	0	0	0	0	0	123 (57.8)	1 (100)	82 (82.0)	0	207 (41.9)
Invasive device access (% of HSE at critical site)	55 (96.5)	30 (100)	29 (100)	9 (75.0)	21 (100)	21 (67.7)	65 (30.5)	0	8 (8.0)	0	238 (48.2)
Mucous membrane (% of HSE at critical site)	1 (1.8)	0	0	3 (25.0)	0	0	0	0	0	0	4 (0.8)
Wound (% of HSE at critical site)	0	0	0	0	0	10 (32.3)	25 (11.7)	0	10 (10.0)	0	45 (9.1)
Infectious risk events	41	42	43	26	44	80	117	31	72	2	508
Patient colonization events	13	26	23	16	25	54	65	30	37	2	291
Patient infection events	38	16	20	10	19	26	52	1	35	0	217
Hand hygiene actions; n	8	13	14	7	11	9	15	4	11	5	97

Table 5: Hand-to-surface exposures and hand hygiene actions (continued)

Video	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	Overall
Hand hygiene action at colonization event; n (% of patient colonization events, i.e. 'adherence')	0	3 (11.5)	2 (8.7)	1 (6.2)	3 (12.0)	2 (3.7)	0	2 (6.7)	1 (2.7)	0	14 (4.8)
Hand hygiene action at infection event; n (% of patient infection events, i.e. 'adherence')	0	0	0	0	0	0	2 (3.9)	0	1 (2.9)	NA	3 (1.4)
Average density of hand hygiene actions; n/hour	13.8	22.4	24.1	11.6	21.1	16.5	26.9	14.4	20.4	18.1	19.6
Mean duration of hand hygiene actions (SD); sec	8.6 (4.7)	14.9 (6.6)	22.2 (11.0)	18.8 (7.4)	11.7 (4.5)	9.2 (4.8)	10.5 (9.6)	16.3 (12.0)	7.9 (3.7)	11.6 (6.2)	13.2 (8.6)

Legend: *HSE* hand-to-surface exposure; *ICU* intensive care unit; *F* female; *M* male; *N* nurse; *P* physician; *NA* not applicable; *SD* standard deviation. Definition for *patient colonization event* and *patient infection event* s. main text

4. Chapter 4: Assessing the clinical relevance of identified infectious risk moments

In this chapter, a method is presented for assessing the clinical relevance of identified infectious risk moments. A modified Delphi method is presented as a method for achieving expert consensus on the likelihood of either patient colonisation or infection following infectious risk moments.

4.1. Study 4: Likelihood of infectious outcomes following Infectious Risk Moments during patient care - an international expert consensus study and quantitative risk index.

Lauren Clack, Simone Passerini, Tanja Manser*, Hugo Sax*

A similar version of this paper has been published:

Clack, L., Passerini, S., Manser, T., & Sax, H. (2018). Likelihood of Infectious Outcomes Following Infectious Risk Moments During Patient Care—An International Expert Consensus Study and Quantitative Risk Index. *Infect Control Hosp Epidemiol, 39*(3), 280-289. doi:10.1017/ice.2017.327.

* Equal contributions as senior authors

ABSTRACT

Objective. Elicit expert consensus on the likelihood of infectious outcomes (patient colonization or infection) following a broad range of infectious risk moments (IRM) that emerged from observations in acute care.

Design. Expert consensus study using modified Delphi technique.

Participants. Panel of 40 international experts including nurses, physicians and microbiologists specialized in infectious diseases and infection prevention and control (IPC).

Methods. The modified Delphi process consisted of three online survey rounds, with feedback of mean ratings and expert comments between rounds. The Delphi survey comprised 52 care scenarios representing observed IRM, organized into six sections: hands, gloves, medical devices, mobile objects, invasive procedures, and additional moments. For each scenario, experts indicated the likelihood of both, patient colonization and infection, on a scale from zero to five (high). Expert ratings were plotted against frequencies of IRM observed during actual patient care resulting in a risk index.

Results. Following three rounds, consensus was achieved for 92 (88.5%) of 104 items. The mean ratings across all scenarios for likelihood of colonization and infection were 2.68 and 2.02, respectively. Likelihood of colonization was rated higher than infection for 48 of 52 scenarios. Ratings were significantly higher for colonization ($p=.001$) and infection ($p<.0005$) when the scenario involved transfer of pathogens to critical patient sites.

Conclusions. The design of effective IPC strategies requires selection of behaviors according to their impact on patient outcomes. The IRM Index reported here provides a basis to standardize and prioritize targets for quality improvement initiatives, training, and future research in acute healthcare.

INTRODUCTION

Healthcare associated infections (HAI) affect hundreds of millions of patients every year worldwide, resulting in prolonged length of hospital stay, long-term disability, high costs to patients and health systems, and excess deaths (WHO, 2011; ECDC, 2015). The causes of such infections are multifactorial. Transmission of microorganisms from a reservoir to a susceptible host plays an important part, as well as interventions that disrupt patients' natural defenses. Within the healthcare setting, potential reservoirs include the pre-existing flora of patients themselves, healthcare workers (HCW), or the physical environment (Bonten et al., 1996; Siegel et al., 2007). *Contact transmission*,(Siegel et al., 2007) whereby microorganisms are transmitted *directly* from an infected person or *indirectly* via contaminated intermediate object (e.g. mobile objects, medical devices (Schultsz et al., 2003; Schabrun & Chipchase, 2006)) or person carrying transient flora (Duckro et al., 2005; Pittet et al., 2006a), has been cited as the most common means of transferring the pathogens that may result in patient colonization and infection (Mayhall, 2012). A recent study found that "infectious risk moments" (IRM), defined as seemingly innocuous yet frequently occurring care manipulations resulting in the potential transfer of pathogens to a patient, occur on average 42.8 times per active patient care hour and 34.9, 36.8, and 56.3 in the intensive care, medical, and emergency wards, respectively (Clack et al., 2018b). These findings suggest that the cumulative risk of negative patient outcomes due to IRM may be significant.

Despite growing interest to understand the role of pathogen transmission in healthcare settings, microbiological studies quantifying the risks associated with specific behaviors, such as IRM, (Clack et al., 2014) are limited (Samore, 2002; Weber & Rutala, 2013). This is perhaps due to the complexity and costs associated with the extensive environmental sampling that would be required to draw the link between behaviors and transmission dynamics. This lack of microbiological evidence likely introduces ambiguity regarding the infectious risks present during clinical care and this ambiguity may present a barrier to safe clinician behavior.

We sought expert consensus from the fields of infectious diseases, infection prevention and control (IPC), and microbiology regarding the likelihood of infectious outcomes in a series of typical care scenarios that were observed during acute care. This companion article, reported in this same issue, describes the results of structured observations to identify the frequency and nature of IRM in acute care settings (Clack et al., 2018b).

We aim to establish a comprehensive inventory of IRM together with expert evaluations of clinical relevance. This inventory will serve the community of researchers and practitioners as a basis for designing and prioritizing future patient safety research, training, and quality improvement initiatives for infection prevention and control.

METHODS

A modified Delphi technique (Hsu & Sandford, 2007) was used to elicit expert opinion on the likelihood of infectious outcomes (i.e. patient colonization or infection) following IRM. Experts were invited to participate in a Delphi process – for an anticipated three rounds, or until consensus was achieved, whichever occurred first. The Delphi process was conducted in an iterative nature with subsequent rounds informed by a feedback summary of group response in the previous round whereby experts could reassess their initial responses. Surveys were distributed electronically using an online tool, allowing participates to remain anonymous and minimize conformity (Hsu & Sandford, 2007).

Participants

We recruited a panel of international experts (nurses, physicians, and microbiologists) specialized in infectious diseases and IPC to represent a broad range of knowledge in the topic of germ transmission. We initially sent an invitation to 59 potential participants explaining the scope of the project and asking that they commit to all rounds of the Delphi process. Individuals who agreed to participate were included in the expert panel.

Survey design

The survey consisted of 52 care scenarios that included a sample of IRM observed during 130 hours of exploratory observations. (Clack et al., 2018b) Each IRM may be represented as a three-part transmission pathway that identifies the surfaces (i.e. source, vector, and endpoint) involved in the potential transmission of pathogens to the patient. Care scenarios were therefore selected to represent the range of observed transmission pathways based on 1) the source of pathogens, 2) the vector of transmission, and 3) the patient site (endpoint) to which the pathogens may be transferred, according to the Infectious Risk Moment Structured Classification Taxonomy (INFORM) (Clack et al., 2018b). We distinguish between endpoints that are *non-critical* sites (e.g. intact skin, intact dressings, patient clothing), *critical sites*, defined as “body sites or medical devices that have to be protected against micro-organisms potentially leading to patient infection” (Sax et al., 2007) (e.g. mucous membranes, catheter insertion sites, open wounds), and *patient bedding*. INFORM excludes transmission pathways that do not end with the patient or patient bed.

The survey included six thematic sections based on the vectors involved, i.e. healthcare workers’ hands, gloves, healthcare workers’ clothing or accessories, invasive devices, medical devices, and mobile objects. The order with which scenarios were presented within each section were block-randomized to avoid order effect biases (Perreault, 1975). The survey included 55 questions, three of which did not include scenarios meeting the current definition of IRM and are not included in this report. For each scenario, experts used a Likert-type scale to indicate the likelihood of patient colonization and patient infection, resulting in ratings for 104 items. Experts rated likelihood using the following scale: 0, none; 1, very low; 2, low; 3, medium; 4, high; or 5, very high. For all scenarios, experts were instructed to make an assessment based on an archetypical ICU patient in an 800-bed academic hospital, for which a description was provided in the survey instructions. A shortened version of the survey has previously been piloted (Clack et al., 2014). Results from the pilot survey are not included in the current manuscript.

Delphi procedure

For each Delphi round, experts received personalized access to the online survey and were instructed to complete the survey within three weeks. Personalized reminders were sent to all experts with partial or missing responses, two and four weeks after each initial invitation.

Round 1: Experts received access to the structured survey with all care scenarios and were instructed to judge the likelihood of 1) patient colonization and 2) patient infection for each scenario. Experts were given the opportunity to provide comments along with their ratings.

Round 2: Experts received access to the structured survey with all care scenarios, as well as a summary of Round 1 results, i.e. the mean ratings for likelihood of colonization and infection for each care scenario. Experts were instructed to revise their judgements or to use the comments section to specify their rational for diverging from the mean ratings.

Round 3: Experts received the structured survey including only care scenarios for which consensus had not been achieved, in order to reduce workload, as well as a feedback summary of Round 2 results, i.e. the mean ratings for likelihood of colonization and infection and the expert comments for each scenario. Experts were instructed that this was likely the final opportunity to revise their ratings and were encouraged to provide comments explaining their ratings.

Analysis

Consensus was defined a-priori as 80% of participant votes falling within two consecutive points on a six-point scale (Ulschak, 1983). Statistical analyses, including measures of central tendency (means, medians, and mode), and comparison of means, were conducted in STATA version 14.2 and SPSS version 23 (Corp., 2013; StataCorp, 2015).

For interpretation of results, we propose a quantitative risk assessment based on Delphi expert ratings together with frequencies of IRM observed in an actual ICU (Clack et al., 2018b). Each scenario from the Delphi survey was classified using the INFORM taxonomy according to the source, vector, and endpoint involved in the portrayed IRM. The frequencies during actual patient care of IRM with the same source, vector and endpoint were extracted from (Clack et al., 2018b) and plotted against expert consensus ratings. By multiplying expert ratings (likelihood of colonization and likelihood of infection) for each IRM by the frequency with which that category of IRM was observed during actual care in the ICU (n/active care hour), we established a quantitative indication of the relative risk represented by each individual IRM, which we term the *IRM Index*.

RESULTS

Following our invitation, 40 experts responded positively and formed our expert panel. The expert panel included physicians (75%, n=30), nurses (17.5%, n=7), and microbiologists (7.5%, n=3) with primary specialization in infection prevention (55%, n=22), microbiology (25%, n=10) and infectious diseases (20%, n=8) and represented the following geographic regions: Europe (67.5%, n=27); The Americas (20%, n=8); and Western Pacific (12.5%, n=5). The participation rates despite two reminders in Delphi rounds one, two and three were 92.5% (physicians 87%, nurses 86%, microbiologists 100%), 87.5% (physicians 80%, nurses 86%, microbiologists 100%), and 75% (physicians 70%, nurses 86%, microbiologists 100%) (**Figure 13**).

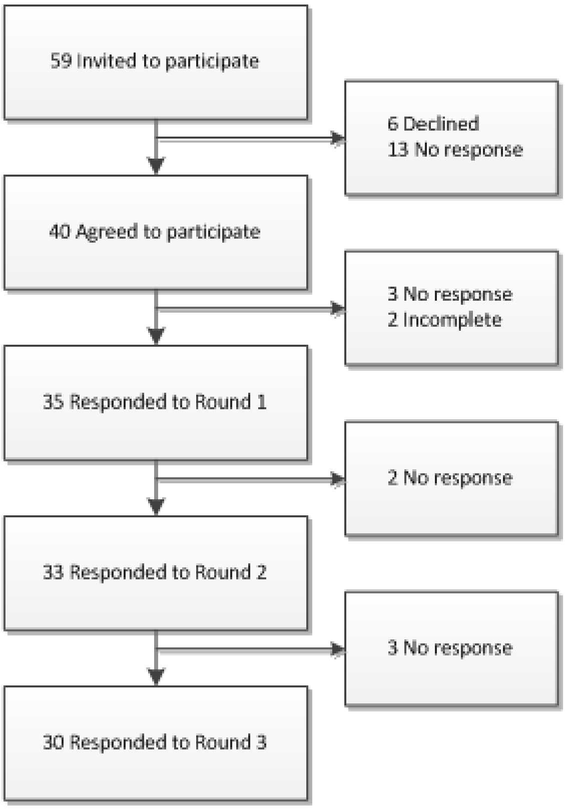

Figure 13: Flow chart demonstrating the participation rate of invited experts

Figure 13 Legend: Flow chart demonstrating the participation rate of invited experts

Following three Delphi rounds, consensus was achieved for 92 (88.5%) of 104 items. Items for which consensus was not achieved concerned 9 colonization ratings and three infection ratings and fell under the categories of invasive (6) and medical devices (2), mobile objects (2), healthcare worker (1), and hands (1). We included all consensus ratings or Delphi round three ratings when the prior was unavailable, as our final ratings for the analysis (**Table 6**). Experts did not conclude that any of the 52 scenarios represented no likelihood of colonization or infection. Expert ratings from all three rounds are reported in **Table 7.**

The mean final ratings across all scenarios for likelihood of colonization and infection were 2.68 (1.73-2.02) and 2.02 (0.97-3.24) (**Table 6**). The final ratings for likelihood of colonization were higher than infection in 48 of 52 scenarios. The four remaining scenarios all concerned moments of potential pathogen transfer to critical sites. A Wilcoxon signed-rank test determined that the increase in ratings for likelihood of colonization compared to likelihood of infection was statistically significant, z=5.92, p<.0005. Further, the mean ratings across all IRM scenarios concerning potential transfer of pathogens to critical patient sites, 2.88 for colonization and 2.51 for infection, were significantly higher than for moments concerning potential transfer of pathogens to non-critical patient sites, 2.39 for colonization (p=.001) and 1.31 for infection (p<.0005). When grouped according to transmission vector, the mean ratings for likelihood of colonization and infection were: hands (colonization=3.02; infection=2.19), gloves (colonization=2.63; infection=2.09), healthcare workers' clothing or accessories (colonization=2.42; infection=1.36), invasive devices (colonization=2.75; infection=2.51), medical devices (colonization=2.46; infection=1.32), and mobile objects (colonization=2.47; infection=1.69). The mean ratings according to source, vector, and endpoint are shown in **Figure 14**.

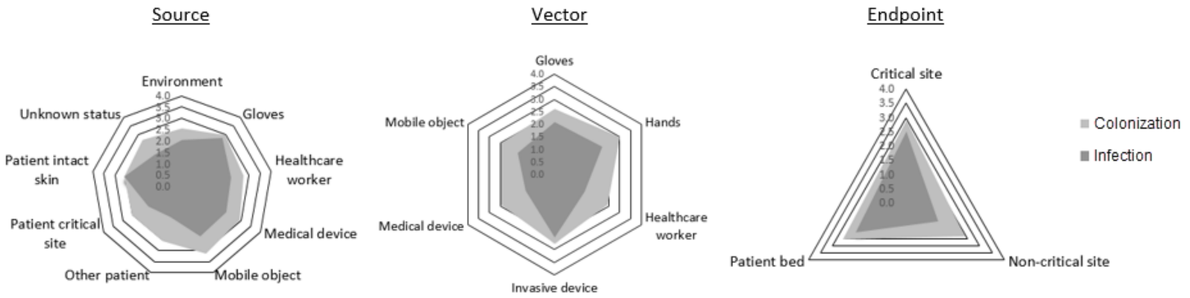

Figure 14: Radial charts of expert ratings according to source, vector, and endpoint

Figure 14 Legend: The three radial charts display the mean expert ratings according to the source (left), vector (middle), and endpoint (right) involved in the infectious risk moment (IRM) scenarios rated by experts. All scenarios were classified by source, vector and endpoint according to the INFORM taxonomy (Clack et al., 2018b). Ratings for colonization are shown in light grey, and ratings for infection in dark grey.

The expert ratings for likelihood of colonization and infection are plotted against frequency data extracted from the companion paper in **Figure 15** (Clack et al., 2018b). The resulting relative risk indices, based on the multiplication of expert ratings and frequency of occurrence during structured observations in an ICU, are shown in **Figure 16**.

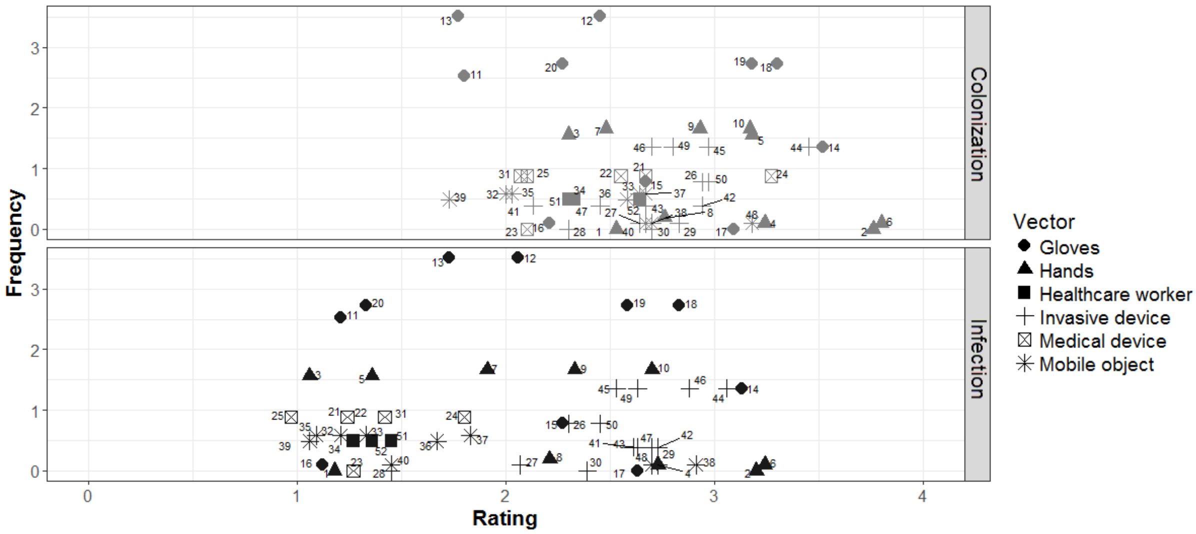

Figure 15: Expert ratings plotted according to frequency, colonization, infection

Figure 15 Legend: All infectious risk moments (IRM) are plotted according to frequency of occurrence (n per hour of active patient care) and expert rating of likelihood of infectious outcomes, colonization (marked in grey) above and infection (marked in black) below. IRM are grouped according to the vectors involved.

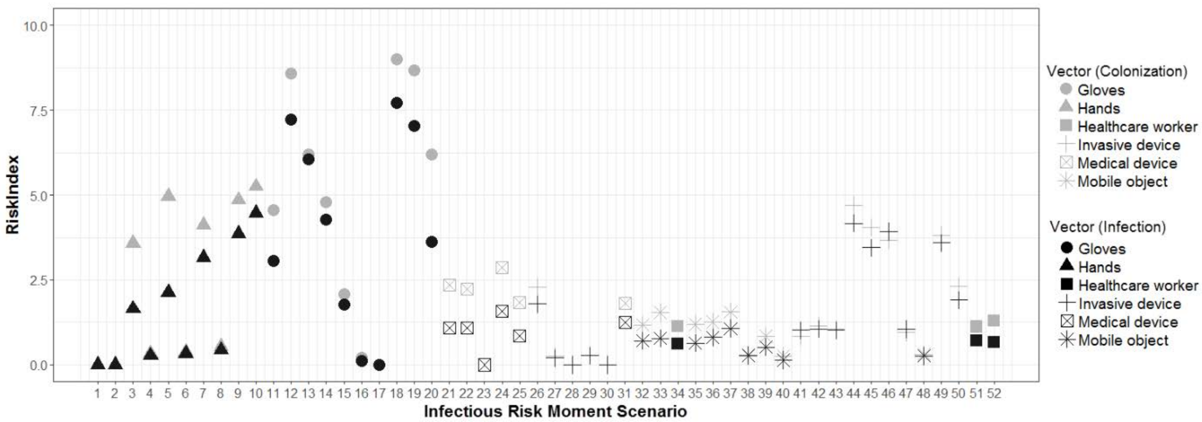

Figure 16: Risk indices for colonisation and infection

Figure 16 Legend: The above figure displays the risk index for colonization (marked in grey) and infection (marked in black) of each individual infectious risk moment (IRM). The *IRM Index* is a multiplication of the frequency with which each IRM occurs (Clack et al., 2018b) and expert ratings of likelihood of negative outcomes, colonization or infection, following the IRM.

DISCUSSION

This modified Delphi expert consensus study revealed low-medium mean ratings for the likelihood of infectious outcomes following a wide range of infectious risk scenarios observed during actual acute care. The fact that none of the 52 scenarios was rated has having no likelihood of infectious outcomes suggests that this group of experts found these IRM to be of clinical relevance. Mean ratings for likelihood of colonization were higher than ratings for likelihood of infection, except when concerning potential pathogen transfer to critical patient body sites. Expert ratings varied particularly according to the source, vector and endpoint involved in the given scenarios (**Figure 14**). Whereas average ratings for likelihood of colonization remained relatively constant across the potential endpoints (range 2.39-2.88), ratings for likelihood of infection were higher for scenarios concerning transfer to patient critical sites (2.51) than to the patient bed (2.08) or non-critical sites (1.31) (**Figure 14**). This is a logical finding because the likelihood of infection is higher when pathogens are transferred directly to a critical site, where the body's natural barrier is already broken (e.g. catheter insertion site) or less resistant (e.g. mucous membranes). Further, whereas the average rating for likelihood of colonization was highest for scenarios involving hands as vectors (3.02), the average rating for likelihood of infection was highest for scenarios involving invasive devices (2.51) as vectors. Concerning the source of pathogens, average ratings for likelihood of colonization were highest among scenarios where mobile objects (3.12), gloves (2.98), and medical devices (2.92) were the sources of pathogens, whereas ratings for likelihood of infection were highest among scenarios where gloves (2.78), the patient's own intact skin (2.59) and the healthcare worker's own body or clothing (2.21) were the source of pathogens. This last finding is of particular interest, given that the patient's own body may be an often-overlooked source of pathogens.

These findings are best appreciated together with the structured observations reported in our companion paper demonstrating that such IRM occur as frequently as 34.9-56.3 times per active care hour, depending on the care setting. Together, these findings suggest that the cumulative risk of such IRM on a system level may indeed present a significant threat to patient safety. The IRM Index, which provides a quantitative indication of relative risk by integrating expert ratings with the frequency of individual IRM during real acute patient care (Clack et al., 2018b), shows a marked and relevant variety in system level infectious risks. The IRM Index, for example, demonstrates that scenarios with the highest expert ratings for likelihood of infectious outcomes did not necessarily have the highest corresponding relative risk indices – due to their rare occurrence during actual patient care. Notable examples include scenarios 2, 6, and 14 (shown to the far right in **Figure 15**), which all include potential pathogen transfer via hands and gloves to patient critical sites, yet occur less than once per hour, resulting in relatively low risk indices (**Figure 16**). In contrast, scenarios with the highest relative risk indices for colonization (e.g. 19, 12) and infection (e.g. 18, 12) were those that combined medium expert ratings of infectious outcomes with high frequency, occurring more than twice per hour of patient care.

These findings exhibit the value of our mixed-method approach, combining expert ratings with observed frequencies to provide a holistic view of infectious risks. The human-factors-informed approach of systematically identifying opportunities for transmission of pathogens also lies at the center of other landmark infection prevention strategies, such as the World Health Organization's "Five Moments" for Hand Hygiene(Pittet et al., 2006a; Sax et al., 2007). While the "Five Moments" model is limited to hands as the primary vector in the bi-directional exchange of microorganisms via contacts with surfaces throughout the healthcare environment, we extend this argumentation to consider the role of gloves, healthcare worker clothing and accessories, invasive devices, medical devices, and mobile objects as vectors.

While others have noted a lack of literature documenting the risks of microbial transmission associated with HCWs' hands during specific care tasks (Pittet et al., 2006a), this applies even more to the other transmission pathways addressed in our work. Thus, the Delphi technique was selected in this study to establish expert consensus in light of limited published evidence, particularly regarding the risks of patient colonization or infection associated with specific behaviors beyond hand hygiene. Specifically, using the Delphi methods over several feedback rounds has the advantage of allowing experts to exchange and reassess opinions to come to an informed consensus decision. Finally, we anticipate that the quantitative approach presented here for identifying specific behaviors associated with transmission and subsequent quantification of the likelihood of infectious outcomes may provide a basis for further quantitative modelling of system level risks.

In the realm of healthcare safety and quality, multiple strategies have been proposed for prioritizing the behaviors addressed by improvement strategies. A critical component of this prioritization is assessing how likely the addressed behavior is to have a positive or negative impact on patient outcomes (Gurses et al., 2009; Michie, Atkins, & West, 2014a). Awareness of the frequency with which infectious risk behaviors occur (Clack et al., 2018b), together with expert consensus regarding the likelihood of infectious outcomes provides a basis for prioritizing the implementation of interventions that prevent the transmission of pathogens. Therefore, we introduced the IRM Index (**Figure 16**), which considers both the likelihood of infectious outcomes at individual IRM, as well as the frequency with which the IRM occur during actual care, to provide a quantitative indication of relative risks on a systems level.

Ambiguity is an important barrier to healthcare worker adherence to guidelines (Gurses et al., 2008a). We suspect that ambiguity regarding likelihood of infectious outcomes following unsafe behaviors prevents healthcare workers from developing accurate risk perceptions (Sax & Clack, 2015). Risk perceptions play a central role in several social cognitive models as a behavioral determinant (Rogers, 1975; Rosenstock et al., 1988; Bandura, 1993). Therefore, we believe that quantifying the risk associated with specific behaviors through expert consensus represents a first step towards removing ambiguity for healthcare workers and towards establishing informed risk perceptions to support safe behavior.

Some limitations of this study should be considered. Although three Delphi rounds were previously suggested as sufficient for achieving consensus (Diamond et al., 2014), we were unable to achieve consensus ratings according to our a-priori definition for 12 (11.5%) items. Further, despite our efforts to avoid anchoring or order-effect biases (Perreault, 1975) through block randomization of survey items, the order of blocks remained the same throughout all surveys and it is possible that expert opinions may by subject to biases and that these may diverge from actual risks as determined through microbiology. Yet, given the current absence of the latter, expert consensus remains the most viable surrogate. It is also worth noting that despite multiple reminders, five experts dropped out during the Delphi process. The ratings of experts who dropped out were insignificantly lower during round one than experts who completed the Delphi process (data not shown). It is unlikely that this significantly influenced our study findings, but should be taken into consideration when interpreting the results. Considering that all IRM scenarios examined were rated as having at least some likelihood of infectious outcome, our findings strongly support the argument to conduct more extensive microbiological studies exploring the actual transmission of microorganisms during patient care activities. Such studies should also further advance the exploration into how frequently infectious outcomes can be attributed to specific behaviors (Duckro et al., 2005; Ludlam et al., 2010; Stiefel et al., 2011).

In conclusion, we believe that this study will contribute to reducing ambiguity regarding the infectious risks associated with common clinical tasks and thus to supporting safe behavior. We further hope that establishing a comprehensive inventory of moments potentially associated with infectious outcomes, together with expert evaluations of clinical relevance will serve the community of researchers and practitioners as a basis for prioritizing future research, training, and quality improvement initiatives.

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Table 6: Expert consensus ratings grouped by vector

Vector (mean ratings)	#	Scenario	Col.*	Inf.*	Source	Endpoint
Invasive device (Colonization: 2.75, Infection: 2.51)	44	A healthcare worker touches the insertion site (already disinfected) of thoracic tubes with non-sterile gloves that had already been worn for an extended period of time touching multiple surfaces, and adjusts the position of the tubes.	**3.45**	**3.06**	Gloves	Critical site
	46	Just before inserting a peripheral venous catheter (PVC), the needle comes into contact with non-sterile disposable examination gloves.	**2.70**	**2.88**	Gloves	Critical site
	29	A three-way valve IV line (connected to an IV line) is left open (uncapped) on a patient's bed.	2.83	**2.73**	Environment	Patient bed
	42	Disinfected skin is touched several times with non-sterile gloves (to locate anatomic structures), before inserting a central venous catheter.	**2.94**	**2.73**	Patient intact skin	Critical site
	47	While inserting a peripheral venous catheter, the same needle is retracted and re-inserted several times at slightly different skin sites in search of the vein.	**2.45**	**2.70**	Patient intact skin	Critical site
	41	A healthcare worker draws blood from a vein in a patient's foot, which is visibly soiled, without prior skin disinfection.	2.13	**2.63**	Patient intact skin	Critical site
	49	A healthcare worker wearing blood-stained, non-sterile disposable examination gloves manipulates a three-way hub of a patient's central vascular line. (Blood is from the same patient)	2.80	2.63	Gloves	Critical site
	43	Prior to inserting a peripheral line, a healthcare worker uses her bare hands (that had not been immediately disinfected) to palpate the patient's vein after the insertion site had already been disinfected.	**2.67**	**2.61**	Patient intact skin	Critical site
	45	A urinary catheter tip is touched with non-sterile disposable examination gloves prior to inserting a urinary catheter.	2.97	2.53	Gloves	Critical site
	50	A healthcare worker prepares to replace a mechanical ventilation tube filter. The healthcare worker opens the new sterile filter with non-sterile disposable examination gloves, places the new filter on the patient's bed, removes the old filter, then picks up the new filter from the bed and attaches it to the ventilation tube.	**2.97**	**2.45**	Environment	Critical site
	30	A three-way valve is placed on a moltex absorbent sheet on a patient's bed. An open lumen of the three-way	**2.70**	**2.39**	Mobile object	Critical site

Vector (mean ratings)	#	Scenario	Col.*	Inf.*	Source	Endpoint
		valve touches the moltex. The three-way valve is then used for an IV-line.				
	26	A healthcare worker disconnects a patient's tracheal tube, places the tube on non-sterile patient bedding, then reconnects the tube again.	**2.94**	**2.30**	Environment	Critical site
	27	The tube connected to a patient's urinary catheter lies on floor, then healthcare worker places it on the patient's bed.	**2.64**	**2.07**	Environment	Patient bed
	28	A healthcare worker places a used suction catheter (used for suctioning of a mechanical ventilation) on the patient's bed (same patient).	**2.30**	**1.45**	Patient critical site	Patient bed
Hands (Colonization: 3.02, Infection: 2.19)	6	A healthcare worker cleans a toilet, touching toilet brush handle with bare hands then, without hand hygiene, touches a patient's open wound.	**3.80**	**3.24**	Mobile object	Critical site
	2	After caring for a first patient, a healthcare worker touches another patient's open wound without hand hygiene.	**3.76**	**3.20**	Other patient	Critical site
	4	A healthcare worker touches her private mobile phone then, without hand hygiene, touches a patient's open wound.	**3.24**	**2.73**	Mobile object	Critical site
	10	After touching parts of her own body and her immediate environment (bedside table, phone, and bed linens), a patient touches her own open wound.	**3.17**	**2.70**	Environment	Critical site
	9	After touching multiple surfaces in the healthcare environment, a healthcare worker enters a patient's room then, without hand hygiene, prepares and administers intravenous medication.	2.93	**2.33**	Environment	Critical site
	8	A healthcare worker touches his face and hair then changes an infusion, without hand hygiene.	**2.76**	**2.21**	Healthcare worker	Critical site
	7	A healthcare worker touches the paper patient records then, without hand hygiene, changes an infusion.	**2.48**	**1.91**	Environment	Critical site
	5	A healthcare worker cleans a toilet, touching toilet brush handle with bare hands then, without hand hygiene, touches patient intact skin.	**3.18**	**1.36**	Mobile object	Non-critical site
	1	After caring for a first patient, a healthcare worker shakes another patient's hand without hand hygiene.	**2.53**	**1.18**	Other patient	Non-critical site
	3	A healthcare worker touches her private mobile phone then, without hand hygiene, touches patient intact skin.	**2.30**	**1.06**	Mobile object	Non-critical site

Vector (mean ratings)	#	Scenario	Col.*	Inf.*	Source	Endpoint
Gloves (Colonization: 2.63, Infection: 2.09)	14	A healthcare worker wearing gloves disposes of a used vomiting bag then inserts a venous cannula while wearing the same pair of gloves.	**3.52**	**3.13**	Mobile object	Critical site
	18	A healthcare worker programs an infusion pump (touch screen) while wearing gloves that had already been worn for an extended period of time, touching multiple surfaces in the room, then manually verifies a central venous catheter insertion site while still wearing the same gloves.	**3.30**	**2.83**	Medical device	Critical site
	17	A healthcare worker disposes of gloves following intimate care, and does not perform hand hygiene prior to continuing patient care and touching patient's open wound.	**3.09**	**2.63**	Patient critical site	Critical site
	19	A healthcare worker programs an infusion pump while wearing gloves that had already been worn for an extended period of time, touching multiple surfaces in the room, then manually verifies a peripheral catheter insertion site while still wearing the same gloves.	**3.18**	**2.58**	Medical device	Critical site
	15	A healthcare worker performs hand hygiene, dons gloves, then examines a patient with open wounds moving from wounds to intact skin and back, wearing the same gloves for the entire examination.	**2.67**	**2.27**	Patient intact skin	Critical site
	12	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, pulls gloves out of the box and dons the gloves then touches patient's open wound	**2.45**	**2.06**	Environment	Critical site
	13	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, carefully and correctly dons sterile surgical gloves without previous hand hygiene then proceeds to insert a central venous line.	**1.77**	**1.73**	Environment	Critical site
	20	A healthcare worker providing intimate care silences an alarm on the patient bedside monitor touchscreen, then continues with intimate care, all with the same pair of gloves.	**2.27**	**1.33**	Medical device	Critical site
	11	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, pulls (non-sterile) gloves out of the box and dons the gloves then touches patient's intact skin.	**1.80**	**1.21**	Environment	Non-critical site

Vector (mean ratings)	#	Scenario	Col.*	Inf.*	Source	Endpoint
	16	A healthcare worker disposes of gloves following intimate care, and does not perform hand hygiene prior to continuing patient care and touching patient's intact skin.	**2.21**	**1.12**	Patient critical site	Non-critical site
Mobile object (Colonization: 2.47, Infection: 1.69)	38	A transfer cannula (plastic piercing spike with finger plate used to mix solutions and medications) is placed on a worktop for temporary storage, and then used again for preparing the next medication.	**2.70**	**2.91**	Environment	Critical site
	48	An open wound is not completely covered by the wound dressing and in consequence, comes into contact with bed linens.	**3.18**	**2.70**	Environment	Critical site
	37	A healthcare worker places a bag of gastric secretions on an intubated and sedated patient's face.	**2.67**	1.83	Unknown status	Non-critical site
	36	Medical-grade adhesive tape is attached to bedrails prior to being used to secure a peripheral line onto the patient's skin.	**2.58**	**1.67**	Environment	Non-critical site
	40	During intimate care, the washcloth being used to clean the patient falls to the floor. The healthcare worker picks it up and continues using it to provide intimate care.	**2.67**	**1.45**	Environment	Critical site
	33	A purpose-built board to facilitate the transfer of patients from a stretcher to a bed (or vice versa) is used on two consecutive patients without disinfection between uses.	**2.64**	**1.33**	Other patient	Non-critical site
	32	A tourniquet is used to draw blood of two consecutive patients without being disinfected between uses.	2.00	**1.21**	Other patient	Non-critical site
	35	A healthcare worker's professional mobile phone, attached to her belt, comes into contact with patient skin during patient examination.	**2.03**	**1.09**	Other patient	Non-critical site
	39	A patient's duvet falls on the floor. A healthcare worker picks up the duvet and puts it back on the patient.	**1.73**	**1.06**	Environment	Non-critical site
HCW (Colonization: 2.42, Infection:: 1.36)	51	A healthcare worker wearing long-sleeved private clothing attends to several patients consecutively. The sleeves of his private clothing come into contact with several patients.	2.30	**1.45**	Other patient	Non-critical site
	52	A healthcare worker wearing a long-sleeved white coat attends to several patients consecutively. The sleeves of his white coat come into contact with several patients.	**2.64**	**1.36**	Other patient	Non-critical site
	34	A healthcare worker's wristwatch comes into contact with the skin of multiple consecutive patients during patient examination.	**2.33**	**1.27**	Other patient	Non-critical site

Vector (mean ratings)	#	Scenario	Col.*	Inf.*	Source	Endpoint
Medical device (Colonization:, 2.46, Infection: 1.32)	24	An x-ray plate with direct contact with patient skin is used on a patient under contact isolation for colonization with Gram-negative multi-resistant Klebsiella pneumophila, then used on a subsequent patient, without being disinfected between uses.	**3.27**	**1.80**	Other patient	Non-critical site
	31	A stethoscope is used on two consecutive patients without being disinfected between uses.	2.07	**1.42**	Other patient	Non-critical site
	23	The electrode multi-use suction cups of an ECG device fall on the floor and then are used on a patient without being disinfected.	**2.10**	**1.27**	Environment	Non-critical site
	21	An x-ray plate with direct contact with patient skin is used on two consecutive patients without being disinfected between uses.	**2.67**	**1.24**	Other patient	Non-critical site
	22	An ECG device including the electrode with multi-use suction cups is used on two consecutive patients without being disinfected between uses.	**2.55**	**1.24**	Other patient	Non-critical site
	25	A blood pressure cuff is used on two consecutive patients without being disinfected between uses.	2.10	**0.97**	Other patient	Non-critical site

Table 6 Legend: The above table indicates the expert consensus ratings based on a Likert-type scale from 0 (none) to 5 (very high), grouped according to the vector involved in pathogen transfer. Groups are sorted in order of descending mean likelihood of infection; questions within groups are sorted by descending likelihood of infection. Col. = likelihood of colonization; Inf. = likelihood of infection; HCW = healthcare workers' clothing or accessories; *ratings for which consensus was achieved are indicated in **bold**.

Table 7: Expert ratings during all Delphi rounds

		Round 1		Round 2		Round 3		Final*		Consensus				
#	Scenario	**col.**	**inf.**	**col.**	**inf.**	**col.**	**inf.**	**col.**	**inf.**	**col.**	**inf.**	**Source**	**Pathway**	**Endpoint**
1	After caring for a first patient, a healthcare worker shakes another patient's hand without hand hygiene.	2.71	1.51	2.45	1.18*	2.53*	--	2.53*	1.18*	yes	yes	Other patient	Hands	Non-critical site
2	After caring for a first patient, a healthcare worker touches another patient's open wound without hand hygiene.	3.86	3.23	3.76*	3.12	--	3.20*	3.76*	3.20*	yes	yes	Other patient	Hands	Critical site
3	A healthcare worker touches her private mobile phone then, without hand hygiene, touches patient intact skin.	2.46	1.49	2.30*	1.06*	--	--	2.30*	1.06*	yes	yes	Mobile object	Hands	Non-critical site
4	A healthcare worker touches her private mobile phone then, without hand hygiene, touches a patient's open wound.	3.34	2.91	3.24*	2.73*	--	--	3.24*	2.73*	yes	yes	Mobile object	Hands	Critical site
5	A healthcare worker cleans a toilet, touching toilet brush handle with bare hands then, without hand hygiene, touches patient intact skin.	3.23	1.86	3.18*	1.36*	--	--	3.18*	1.36*	yes	yes	Mobile object	Hands	Non-critical site
6	A healthcare worker cleans a toilet, touching toilet brush handle with bare hands then, without hand hygiene, touches a patient's open wound.	4.06	3.49	3.94	3.24*	3.80*	--	3.80*	3.24*	yes	yes	Mobile object	Hands	Critical site
7	A healthcare worker touches the paper patient records then, without hand hygiene, changes an infusion.	2.34	2.09	2.48*	1.91*	--	--	2.48*	1.91*	yes	yes	Environment	Hands	Critical site
8	A healthcare worker touches his face and hair then changes an infusion, without hand hygiene.	2.77	2.57	2.76*	2.21*	--	--	2.76*	2.21*	yes	yes	Healthcare worker	Hands	Critical site
9	After touching multiple surfaces in the healthcare environment, a healthcare worker enters a patient's room then, without hand hygiene, prepares and administers intravenous medication.	3.09	3.09	2.97	2.55	2.93	2.33*	2.93	2.33*	no	yes	Environment	Hands	Critical site
10	After touching parts of her own body and her immediate environment (bedside table, phone, and bed linens), a patient touches her own open wound.	3.17	2.91	3.18	2.70*	3.17*	--	3.17*	2.70*	yes	yes	Environment	Hands	Critical site
11	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, pulls (non-sterile) gloves out of the box and dons the gloves then touches patient's intact skin.	2.20	1.40	1.97	1.21*	1.80*	--	1.80*	1.21*	yes	yes	Environment	Gloves	Non-critical site
12	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, pulls gloves out of the box and dons the gloves then touches patient's open wound	2.71	2.34	2.45*	2.06*	--	--	2.45*	2.06*	yes	yes	Environment	Gloves	Critical site
13	After having touched several surfaces in the healthcare environment, a healthcare worker enters a patient room then, without hand hygiene, carefully and correctly dons sterile surgical gloves without previous hand hygiene then proceeds to insert a central venous line.	2.09	1.89	2.00	1.73*	1.77*	--	1.77*	1.73*	yes	yes	Environment	Gloves	Critical site
14	A healthcare worker wearing gloves disposes of a used vomiting bag then inserts a venous cannula while wearing the same pair of gloves.	3.51	3.20	3.52*	3.06	--	3.13*	3.52*	3.13*	yes	yes	Mobile object	Gloves	Critical site

Table 7: Expert ratings during all Delphi rounds

		Round 1		Round 2		Round 3		Final*		Consensus				
#	Scenario	col.	inf.	col.	inf.	col.	inf.	col.	inf.	col.	inf.	Source	Pathway	Endpoint
15	A healthcare worker performs hand hygiene, dons gloves, then examines a patient with open wounds moving from wounds to intact skin and back, wearing the same gloves for the entire examination.	2.66	2.31	2.67*	2.09	--	2.27*	2.67*	2.27*	yes	yes	Patient intact skin	Gloves	Critical site
16	A healthcare worker disposes of gloves following intimate care, and does not perform hand hygiene prior to continuing patient care and touching patient's intact skin.	2.23	1.46	2.21*	1.12*	--		2.21*	1.12*	yes	yes	Patient critical site	Gloves	Non-critical site
17	A healthcare worker disposes of gloves following intimate care, and does not perform hand hygiene prior to continuing patient care and touching patient's open wound.	3.06	2.66	3.09*	2.39	--	2.63*	3.09*	2.63*	yes	yes	Patient critical site	Gloves	Critical site
18	A healthcare worker programs an infusion pump (touch screen) while wearing gloves that had already been worn for an extended period of time, touching multiple surfaces in the room, then manually verifies a central venous catheter insertion site while still wearing the same gloves.	3.29	2.97	3.30*	2.58	--	2.83*	3.30*	2.83*	yes	yes	Medical device	Gloves	Critical site
19	A healthcare worker programs an infusion pump while wearing gloves that had already been worn for an extended period of time, touching multiple surfaces in the room, then manually verifies a peripheral catheter insertion site while still wearing the same gloves.	3.20	2.83	3.18*	2.58*	--	--	3.18*	2.58*	yes	yes	Medical device	Gloves	Critical site
20	A healthcare worker providing intimate care silences an alarm on the patient bedside monitor touchscreen, then continues with intimate care, all with the same pair of gloves.	2.51	1.80	2.27*	1.33*	--	--	2.27*	1.33*	yes	yes	Medical device	Gloves	Critical site
21	An x-ray plate with direct contact with patient skin is used on two consecutive patients without being disinfected between uses.	2.83	1.40	2.67*	1.24*	--	--	2.67*	1.24*	yes	yes	Other patient	Medical device	Non-critical site
22	An ECG device including the electrode with multi-use suction cups is used on two consecutive patients without being disinfected between uses.	2.89	1.54	2.55*	1.24*	--	--	2.55*	1.24*	yes	yes	Other patient	Medical device	Non-critical site
23	The electrode multi-use suction cups of an ECG device fall on the floor and then are used on a patient without being disinfected.	2.54	1.40	2.33	1.27*	2.10*	--	2.10*	1.27*	yes	yes	Environment	Medical device	Non-critical site
24	An x-ray plate with direct contact with patient skin is used on a patient under contact isolation for colonization with Gram-negative multi-resistant Klebsiella pneumophila, then used on a subsequent patient, without being disinfected between uses.	3.31	1.94	3.27*	1.79	--	1.80*	3.27*	1.8*	yes	yes	Other patient	Medical device	Non-critical site
25	A blood pressure cuff is used on two consecutive patients without being disinfected between uses.	2.60	1.26	2.12	0.97*	2.10	--	2.10	0.97*	no	yes	Other patient	Medical device	Non-critical site
26	A healthcare worker disconnects a patient's tracheal tube, places the tube on non-sterile patient bedding, then reconnects the tube again.	2.94	2.51	2.94*	2.27	--	2.30*	2.94*	2.30*	yes	yes	Environment	Invasive device	Critical site
27	The tube connected to a patient's urinary catheter lies on floor, then healthcare worker places it on the patient's bed.	2.80	2.06	2.64*	2.06	--	2.07*	2.64*	2.07*	yes	yes	Environment	Invasive device	Patient bed

Table 7: Expert ratings during all Delphi rounds

		Round 1		Round 2		Round 3		Final*		Consensus				
#	Scenario	col.	inf.	col.	inf.	col.	inf.	col.	inf.	col.	inf.	Source	Pathway	Endpoint
28	A healthcare worker places a used suction catheter (used for suctioning of a mechanical ventilation) on the patient's bed (same patient).	2.54	1.86	2.30*	1.45*	--	--	2.30*	1.45*	yes	yes	Patient critical site	Invasive device	Patient bed
29	A three-way valve IV line (connected to an IV line) is left open (uncapped) on a patient's bed.	3.03	3.00	2.36	2.48	2.83	2.73*	2.83	2.73*	no	yes	Environment	Invasive device	Patient bed
30	A three-way valve is placed on a moltex absorbent sheet on a patient's bed. An open lumen of the three-way valve touches the moltex. The three-way valve is then used for an IV-line.	3.00	2.89	2.70*	2.39*	--	--	2.70*	2.39*	yes	yes	Mobile object	Invasive device	Critical site
31	A stethoscope is used on two consecutive patients without being disinfected between uses.	2.86	1.57	2.24	1.42*	2.07	--	2.07	1.42*	no	yes	Other patient	Medical device	Non-critical site
32	A tourniquet is used to draw blood of two consecutive patients without being disinfected between uses.	2.60	1.46	2.27	1.21*	2.00	--	2.00	1.21*	no	yes	Other patient	Mobile object	Non-critical site
33	A purpose-built board to facilitate the transfer of patients from a stretcher to a bed (or vice versa) is used on two consecutive patients without disinfection between uses.	2.71	1.57*	2.64*	1.33*	--	--	2.64*	1.33*	yes	yes	Other patient	Mobile object	Non-critical site
34	A healthcare worker's wristwatch comes into contact with the skin of multiple consecutive patients during patient examination.	2.63	1.40	2.33*	1.27*	--	--	2.33*	1.27*	yes	yes	Other patient	Healthcare worker	Non-critical site
35	A healthcare worker's professional mobile phone, attached to her belt, comes into contact with patient skin during patient examination.	2.09	1.17	2.03*	1.09*	--	--	2.03*	1.09*	yes	yes	Other patient	Mobile object	Non-critical site
36	Medical-grade adhesive tape is attached to bedrails prior to being used to secure a peripheral line onto the patient's skin.	2.54	1.89	2.58*	1.67*	--	--	2.58*	1.67*	yes	yes	Environment	Mobile object	Non-critical site
37	A healthcare worker places a bag of gastric secretions on an intubated and sedated patient's face.	2.74	2.00	2.67*	1.91	--	1.83	2.67*	1.83	yes	no	Unknown status	Mobile object	Non-critical site
38	A transfer cannula (plastic piercing spike with finger plate used to mix solutions and medications) is placed on a worktop for temporary storage, and then used again for preparing the next medication.	2.69	2.83	2.82	2.91*	2.70*	--	2.70*	2.91*	yes	yes	Environment	Mobile object	Critical site
39	A patient's duvet falls on the floor. A healthcare worker picks up the duvet and puts it back on the patient.	2.31	1.40	1.97	1.06*	1.73*	--	1.73*	1.06*	yes	yes	Environment	Mobile object	Non-critical site
40	During intimate care, the washcloth being used to clean the patient falls to the floor. The healthcare worker picks it up and continues using it to provide intimate care.	2.80	1.77	2.67*	1.45*	--	--	2.67*	1.45*	yes	yes	Environment	Mobile object	Critical site
41	A healthcare worker draws blood from a vein in a patient's foot, which is visibly soiled, without prior skin disinfection.	2.43	2.91	2.39	2.82	2.13	2.63*	2.13	2.63*	no	yes	Patient intact skin	Invasive device	Critical site
42	Disinfected skin is touched several times with non-sterile gloves (to locate anatomic structures), before inserting a central venous catheter.	2.91	2.89	2.94*	2.76	--	2.73*	2.94*	2.73*	yes	yes	Patient intact skin	Invasive device	Critical site
43	Prior to inserting a peripheral line, a healthcare worker uses her bare hands (that had not been immediately disinfected) to palpate the patient's vein after the insertion site had already been disinfected.	3.06	2.80	3.03	2.61*	2.67*	--	2.67*	2.61*	yes	yes	Patient intact skin	Invasive device	Critical site

Table 7: Expert ratings during all Delphi rounds

		Round 1		Round 2		Round 3		Final*		Consensus				
#	Scenario	col.	inf.	col.	inf.	col.	inf.	col.	inf.	col.	inf.	Source	Pathway	Endpoint
44	A healthcare worker touches the insertion site (already disinfected) of thoracic tubes with non-sterile gloves that had already been worn for an extended period of time touching multiple surfaces, and adjusts the position of the tubes.	3.54	3.11	3.45*	3.06*	--	--	3.45*	3.06*	yes	yes	Gloves	Invasive device	Critical site
45	A urinary catheter tip is touched with non-sterile disposable examination gloves prior to inserting a urinary catheter.	3.06	2.94	3.03	2.82	2.97	2.53	2.97	2.53	no	no	Gloves	Invasive device	Critical site
46	Just before inserting a peripheral venous catheter (PVC), the needle comes into contact with non-sterile disposable examination gloves.	2.69	2.83	2.70*	2.88*	--	--	2.70*	2.88*	yes	yes	Gloves	Invasive device	Critical site
47	While inserting a peripheral venous catheter, the same needle is retracted and re-inserted several times at slightly different skin sites in search of the vein.	2.57	2.77	2.45*	2.94	--	2.70*	2.45*	2.70*	yes	yes	Patient intact skin	Invasive device	Critical site
48	An open wound is not completely covered by the wound dressing and in consequence, comes into contact with bed linens.	3.03	2.63	3.18*	2.7*	--	--	3.18*	2.70*	yes	yes	Environment	Mobile object	Critical site
49	A healthcare worker wearing blood-stained, non-sterile disposable examination gloves manipulates a three-way hub of a patient's central vascular line. (Blood is from the same patient)	3.49	3.31	3.00	2.94	2.80	2.63	2.80	2.63	no	no	Gloves	Invasive device	Critical site
50	A healthcare worker prepares to replace a mechanical ventilation tube filter. The healthcare worker opens the new sterile filter with non-sterile disposable examination gloves, places the new filter on the patient's bed, removes the old filter, then picks up the new filter from the bed and attaches it to the ventilation tube.	2.97	2.46	2.97	2.45*	2.97*	--	2.97*	2.45*	yes	yes	Environment	Invasive device	Critical site
51	A healthcare worker wearing long-sleeved private clothing attends to several patients consecutively. The sleeves of his private clothing come into contact with several patients.	2.69	1.57	2.55	1.45*	2.30	--	2.30	1.45*	no	yes	Other patient	Healthcare worker	Non-critical site
52	A healthcare worker wearing a long-sleeved white coat attends to several patients consecutively. The sleeves of his white coat come into contact with several patients.	2.57	1.63	2.64*	1.36*	--	--	2.64*	1.36*	yes	yes	Other patient	Healthcare worker	Non-critical site

5. Chapter 5: Empirical methods for understanding behavioural determinants

The following chapter presents three studies employing various methods to empirically explore the factors that influence HCP behaviours relevant to infectious risks.

The first two papers in this chapter (sections 5.1 and 5.2) report on the development and execution of a concept-mapping technique to understand HCP mental models relative to infectious risks. “Mental models”, broadly defined as internal mental representations based on previous experiences of how things work that shape the way an individual behaves, have been proposed as a useful concept to understand HCP infection prevention behaviours (Sax & Clack, 2015). Individual mental models about how things work are reflections of that individual’s beliefs, but these beliefs may be flawed or inaccurate, leading to undesired or unsafe behaviours. Mapped onto the TDF, the beliefs and mental concepts that make up individual mental models would primarily fall under domains such as “beliefs about consequences” (e.g. mental models about consequences of missing infection prevention behaviour) and “knowledge” (e.g. mental models about infection prevention rules). In general, individual reliance on mental models for making quick decisions when cognitive resources are limited would fall under the TDF domain, “memory, attention and decision processes”. The first paper in this chapter reports on the iterative development of a methodology to explore individual mental models using a card-sorting technique combined with a think-aloud protocol. Because individual mental models about what items in the physical environment make up the “patient zone” emerged as in important topic, as discussed in chapters 3 and 4, the second paper in this chapter reports on the utilisation of the concept-mapping technique to explore mental models about the patient zone.

The third and final paper in this chapter reports on an extensive video-reflexive ethnography study with 40 HCP from four unique care settings to explore the factors that influence behaviours relative to infectious risk moments. The TDF was used as the guiding theoretical framework for this study. The analysis of these interviews is currently ongoing. The preliminary results and implications are discussed.

5.1. Study 5: Iterative development of concept mapping technique to reveal healthcare provider mental models of infectious risks.

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A similar version of this paper is under revision.

ABSTRACT

Traditional interventions to improve adherence with hospital infection prevention measures typically consist of educational efforts and campaigns aimed at increasing healthcare provider knowledge and motivation. We suggest, however, that much of the healthcare provider behaviour is automatic, driven by subconscious mental models. These mental models enable individuals to understand the world around them, predict the future, and support decision-making. Understanding healthcare provider mental models, for example regarding infectious risks, is crucial to designing interventions that support safe infection prevention behaviours and promote patient safety. Since it is not possible to ask individuals directly about such subconscious, underlying processes we report on the development and application of a concept mapping study using a card-sorting technique to elicit healthcare provider mental models. The aim of this study was to assess the feasibility of this methodology.

INTRODUCTION

Healthcare-associated infections constitute a major risk for patient safety and may prolong length of stay in hospital, result in patient suffering, raise morbidity and mortality and increase costs (Cosgrove, 2006; Graves et al., 2007). A significant portion of healthcare-associated infections may be prevented through the application evidence-based measures, such as hand hygiene, utilization of aseptic technique, isolation precautions, and disinfection of medical devices between patients (Sax et al., 2007; Siegel et al., 2007; O'Grady et al., 2011). Yet, such measures are not always systematically applied (Carling, Briggs, Hylander, & Perkins, 2006). Many efforts to enhance hand hygiene, often consisting of education or information campaigns, are based on the assumption that there is a lack of knowledge or motivation to adhere to existing guidelines (Gould, Moralejo, Drey, Chudleigh, & Taljaard, 2017).

We propose, however, that much of healthcare provider behavior is automatic, driven by subconscious mental models (Sax & Clack, 2015). Mental models are internal images an individual gains through experience and observation (Johnson-Laird, 1986). They result in ‘small-scale models’ (Craik, 1943a) of the external reality and can be projected onto following experiences, helping to understand them and make predictions of the future and thereby support decision making processes. Mental models build the foundation of how humans understand and operate in this world but it is crucial to keep in mind that they are in no way complete or faultless representations of the real world (Sterman, 2006). Instead, they offer simplistic solutions to handle complex situations and thereby enable more rapid and intuitive decisions (Sax & Clack, 2015).

Because individual mental models may be an important driver of individual behaviors, it is important to transform these tacit mental models into explicit knowledge so that it can be shared between individuals and transfer it from an individual to organizational level.

Specifically, understanding healthcare provider mental models, for example, about how healthcare associate infections occur and about the role of preventative behaviors, may offer important insights when designing infection prevention initiatives. Understanding existing mental models may be of particular interest because these can be faulty, or diverge from local guidelines, leading to unsafe behavior. Given that it is not possible to simply ask people what subconscious mental models they have, methods to explore and detect underlying mental models are needed. One such method consists in concept mapping through the application of a card-sorting technique.

Concept mapping can be divided into three different types, including word-based, graphic-based, and framework-based techniques, in which participants are prompted with various items and instructed to arrange them into a map of interrelated concepts (Steiger & Steiger, 2017). In our study, we used the word-based exercise, which is often applied in combination with a card-sorting technique, to reveal experiences, perceptions, assumptions, knowledge, and subjective beliefs. This concept can be traced back to the early 1970's at the Cornell University (Butler-Kisber & Poldma, 2010). The card-sorting technique is a method to analyze human behavior or individual cognition, enabling researchers to understand how individuals think and what concepts lie beneath their thinking. To validate card-sorting sessions it is possible to involve thematic experts and compare their sorting with the sorting of the participants (Budhwar, 2000).

We undertook a study to assess the utility of a concept mapping exercise using card-sorting technique to explore mental models of healthcare providers. We did this within the context of a larger study specifically examining healthcare provider behaviors that are relevant for infection prevention (Clack et al., 2014). With the infection prevention context in mind, we sought to iteratively develop and optimize a card-sorting technique that would allow to explore healthcare provider mental models about infectious risks in acute care settings. The following article describes the iterative development and testing of the methodology, as well as preliminary results that emerged from the study, and finally some suggestions for further analysis of card-sorting results. The aim of this study is therefore not to draw definitive conclusions about healthcare provider mental models, rather to highlight the methodological approach and assess its utility for further applications.

METHODS

Study design

An iterative and explorative study design was chosen to develop and assess the feasibility of concept mapping using the card-sorting technique to examine healthcare provider mental models about infectious risks.

Participants

We included a convenience sample of clinicians who were available on the days interviews were being conducted. Participants were recruited from a general medical ward and the infectious diseases department. We purposefully selected this mix of participants to include individuals trained and familiar with infection prevention, as well as individuals without specialty training in infection prevention. Data collection continued until saturation, that is, until no further ideas for improvement of the methodology arose, as discussed below.

Procedure

The interviews and card-sorting sessions were conducted as semi-structured interviews and took place between April and May 2017. The general structure of the concept-mapping activity was as follows: 1) the researcher gave background information about the study and explained the procedure; 2) participants were provided with several scenarios of realistic care situations; and 3) participants were given a set of “factor” cards and instructed to sort the cards according to how the listed factors influenced the likelihood of patient infectious outcomes (**Table 8**). Participants were instructed to "think-aloud" (Davey, 1983) throughout the activity, revealing their thought process throughout the sorting activity. As the goal of this study was to refine the methodology, we conducted the card-sorting sessions and interviews in an iterative process, with insights from each session informing modifications of the next. Two researchers with training in psychology (AB, LC) and familiar with the infection prevention context performed data collection. We videotaped the interviews and card-sorting sessions so that it was possible to attribute the spoken word from the interviews to what was happening in the card-sorting process. At the end of the session, we took a picture from the sorted cards to document their final position.

Following each interview, the two researchers addressed any challenges that arose and discussed how the methodology could be improved for future sessions. These improvements were then integrated and assessed in subsequent interviews. This iterative process continued until both researchers were satisfied with the process and no further ideas for improvement came up.

Table 8: Factors influencing likelihood of patient infection outcomes listed on cards to be sorted

Defenses against infection	Infection defense of the patient (incl. immunity, skin, coughing, etc.)
	Infection defense of the healthcare provider (incl. immunity, skin, coughing, etc.)
	Natural flora/colonization of the patient
Germs	Infectious potential of microorganisms (bacteria, viruses, etc.)
	Antibiotic resistance of microorganisms (bacteria, viruses, etc.)
	Transmissibility of microorganisms (bacteria, viruses, etc.)
	Survival of microorganisms on surfaces
Work environment	Ergonomics of the work environment (how well equipped, layout, architecture, etc.)
	Ergonomics of instruments/ mobile objects (how practical, where available, etc.)
Work procedure	Unconscious vs. conscious behavior
	Work rhythm (incl. Workflow, interruptions, etc.)
	Organization/ Preparation of work procedure
	Priorities during work
	Technical skills
	Knowledge and training

Ethics

The cantonal ethics committee granted a waiver for a formal ethics evaluation for this study according to the Swiss law on research involving humans (KEK-StV-Nr. 73/14). Participation was voluntary and informed consent was provided by the participants.

RESULTS

A total of four semi-structured interviews were conducted with 3 nurses, 1 last year medical resident who were free on the interview days. All of them were female between 25-41 years of age. Experience on the job varied from 2 month to 10 years. Methodological improvements were added after the first and second interview, until a final procedure was established and used in interviews three and four, as described in the sections below and summarized in **Table 9.**

Procedure for the first interview

The interviewer read scenarios based on actual patient care situations to the participant. In a next step, the participant received a set of cards displaying possible influencing factors (**Table 8**) and was asked to physically sort them into one of two categories, “has an influence” or “has no influence”. In addition, the participant was provided the opportunity to list any additional influencing factors on blank cards if needed. The third step was for the participant to explain her choice why she thinks that these factors have or have no influence. Finally, she had to sort the cards into a hierarchical order from highest influence to lowest influence and “think aloud” during this task. For this first interview, nine scenarios were planned but due to time constraints and the unanticipated length of time necessary to complete the task, only five scenarios were used and we ended the session after one hour. After a discussion among the research team, we decided to reduce the number of scenarios from nine to five. Further, it turned out that the sorting into “has an influence” and “has no influence” was not ideal because it is not possible to sort something hierarchically that has no influence. Because we aimed to have all cards ordered, we introduced an influence rating scale with poles ranging from – (minus) “has no influence” to + (plus) “has an influence” onto which all cards should be sorted.

Table 9: Overview of procedure during each session

	Interview 1	**Interview 2**	**Interview 3**	**Interview 4**
Number of scenarios	9 planned, 5 carried out	5 planned, 3 carried out	3 planned, 3 carried out	3 planned, 3 carried out
Number of influencing factors	20	20	15	15
Sorting task	First, sort factors into 2 categories (has an influence; has no influence). Second, rank in hierarchical order (highest influence to lowest influence)	Sort factors on an influence rating scale with poles ranging from minus (has no influence) to plus (has an influence)	Sort factors in a line with poles ranging from ‘has a minor influence’ to ‘has an important influence’, or assign to the category “no influence”	Sort factors in a line with poles ranging from ‘has a minor influence’ to ‘has an important influence’, or assign to the category “no influence”

Procedure for the second interview

The procedure for the second interview remained largely the same as in interview 1, with the exception that the amount of scenarios was reduced and the sorting technique was conducted as described above. Nevertheless, the planned five scenarios could not be completed in the time allotted for the interview. We were able to go through only three scenarios in a one-hour session. The second participant also found it challenging to deal with all 20 factor cards to be sorted. Hence, again, we decided to reduce the number of scenarios to three and the number of factors to 15. The remaining 15 factor cards were also color-coded according to four categories to facilitate their identification. These categories included “defenses against infection”, “germs”, “work environment”, and “work procedure” (**Table 8**). Further, because it became clear that cards with “no influence” could not be ranked onto the scale, rather these were placed in a stack at the minus end of the scale, we re-introduced the option for participants to sort cards into a “no influence” category. We modified the poles of the influence rating scale accordingly to “has a minor influence” and “has an important influence”.

Procedure for the third and fourth interview

The third and fourth interview needed only minor adjustments. The participants both had to read the scenarios aloud for themselves and then go through the set of cards and distribute them onto the influence rating scale. During the sorting task, participants already had the option to either sort the factors onto the scale, ranging from “has a minor influence” to “has an important influence” or place them into the additional category, “no influence,” as shown in **Figure 17**.

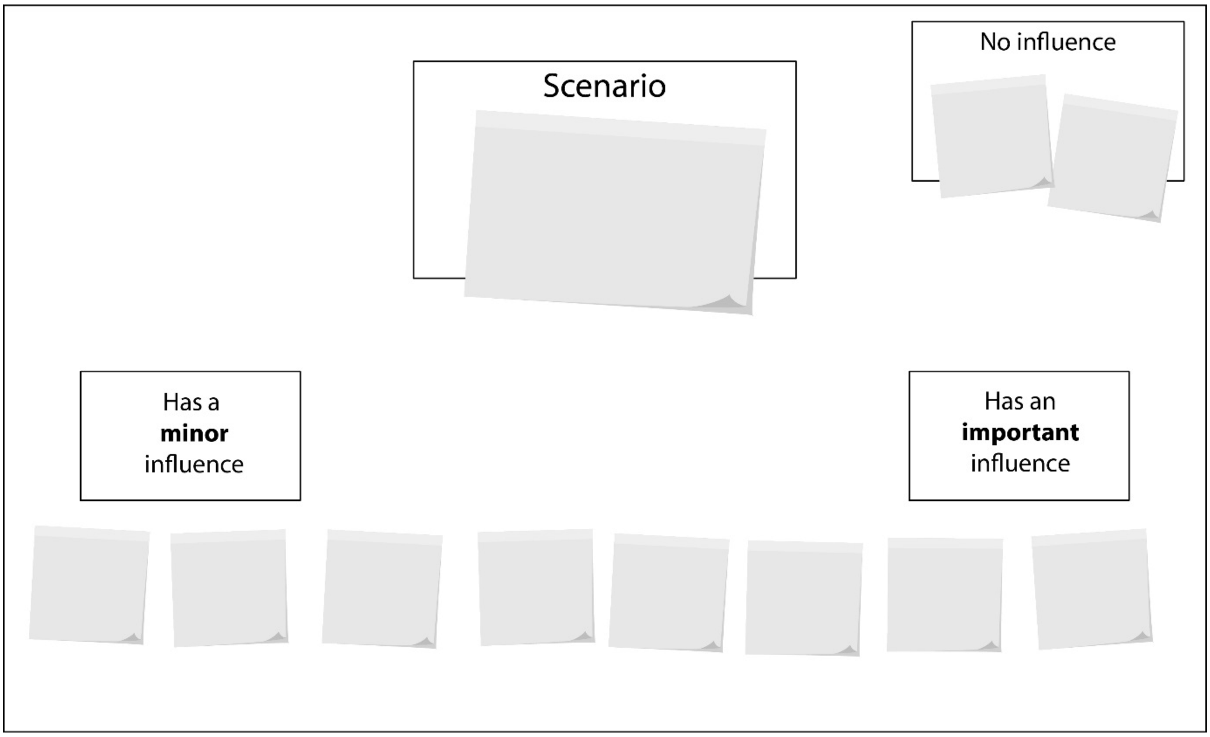

Figure 17: Layout of concept-mapping exercise

Transcript excerpt from one card-sorting session

The iterative process we applied allowed us to develop an adequate procedure for our concept mapping study and refine our interview sessions. Below is an example transcript excerpt from the third interview that was conducted with a registered nurse from a general medical department. This example shows how the interviewer asks the participant to read the scenario and identify the potential risk behavior. The participant is then instructed to sort the factor cards onto the rating scale. Furthermore, this excerpt demonstrates how the interviewer asks additional questions to gain a deeper insight in the thinking process of the participant – exploring her mental models.

Interviewer: Okay, thank you. May I ask you to read aloud the second scenario?

Interviewee: A nurse is changing a central venous catheter bandage (CVC-bandage). She takes the CVC-bandage out of the aseptic packaging then she disinfects her hands and puts on gloves. Just as she is ready to apply the bandage, her beeper goes off. With her gloves on, she takes the beeper out of her pocket and hands it to her colleague to take the call. Without changing gloves, she continues to take the bandage out of the package and puts it on the puncture.

Interviewer: And now please answer the following question. Which action, if any, in this scenario could be a risk for an infection? Could you rank this risk on a scale from 0 = no risk to 5 = very high risk and give an explanation for your ranking?

Interviewee: So what happens is that she takes the beeper and does not change her gloves afterwards. I will give this a five because it goes directly into the central vascular system and I have no idea where this beeper was before. If she does this already when working on a CVC then I don't know where else she did it too [not changing gloves]. That is not good.

Interviewer: Again, I have the factors here for you. Please, always refer to the scenario when stating how important their influence is.

Interviewee: "Natural flora/ colonization" has an important influence (puts the card to the right side). Is it okay if I first make a preliminary arrangement of the cards and later do the refinement?

Interviewer: Sure, whatever works best for you.

Interviewee: Definitely, “priorities during work”. Because you can for once not answer the beeper or she could have leaned over so that her colleague can take the beeper out of her pocket. “Transmission of microorganisms” has an influence (puts it rather to the left side). “Knowledge and training” (thinks about it then puts it aside). […] “Organization/ preparation of work procedure” has no influence (puts it aside). […] “Technical skills”, no (puts the card aside). “Survival of microorganisms on surfaces”, that is right (puts it to the right side). […] “Infection defense, or immunity" of the patient”, oh yes (puts the card to the right side). […] “Unconscious vs. conscious behavior”, no because she touched the beeper consciously and gave it to her colleague, that was not necessary (puts it on the left side).

Interviewer: Could you explain your decision, please?

Interviewee: Well, “technical skills” have nothing to do with touching the beeper. “Organization/ preparation of work procedure”, one can never know when the beeper will go off but she should not have touched it. […] Then, “knowledge and training”, it is difficult to say if this has an influence. Because, I think, that she has learned that after putting on gloves she cannot touch other things anymore. That is why I do not know if it has an influence or not. I hope that she did not do it because of a lack of knowledge. Okay, I will put it in the middle. Then I will go from right to left. I waiver between “flora” and “priorities during work”, which has a more important influence. On one hand, it has consequences for the patient if he has a poor [immune] defense (points on flora). On the other hand her “priorities during work”, despite of her work she touched the beeper. […]

Interviewer: You can write on the supplemental cards if you have more ideas about what could have an influence.

Interviewee: No. I think that “priorities during work” are very important.

[…]

Interviewer: Do you have any ideas about what could be the reason for this behavior?

Interviewee: Maybe she did not think about that she should change the gloves or she did not care about it. On the other hand, she could argue; in that case, you should also disinfect a pen after touching it. I would say that if you were caring for a patient you should first disinfect your hands before you touch a pen. Maybe it was just inattention.

DISCUSSION

The iterative process used to develop and test the feasibility of concept mapping using the card-sorting technique to explore mental models of healthcare providers led us to several insights. First, the findings of this study suggest that this is indeed an adequate methodology to explore healthcare providers' mental models. When considering this methodology for more extensive studies, it would be important to have a larger sample size to ensure sufficient data for drawing conclusions. Due to our small sample size, we were not able to conduct a quantitative or qualitative analysis that would provide meaningful results. Our study also identified some challenges that should be considered. For example, it was not possible to show the participants more than three scenarios due to the task being very time consuming. Also, the number of factors had to be reduced to 15 because otherwise task was too cognitively demanding. As a solution, participant feedback indicated that having the factor cards colored according to the four categories (**Table 8**) helped to make the distinction more obvious and did facilitate the task.

Furthermore, it is crucial to keep in mind that complex topics may result in very complex studies that might be cognitively demanding for the participants. Another point that plays a major role for the success of the study is to make sure that the participants do not misunderstand the study as a knowledge test. Sorting such terms into a certain order might easily give participants the impression that there is a right and a wrong way to do it. Although this card-sorting session is also an interview session, acknowledgement expressions and utterances such as e.g. "mhmm" which are often used in interview settings to demonstrate active listening (Rogers & Farson, 2015) to the interviewee, should be kept to a minimum. They might convey the impression that the sorting process is correct or false. In addition, we recommend managing the time during data collection. Some participants like to discuss things into details. Although, this is usually positive in interviews, it might lead the card-sorting session to run over the scheduled time. Lastly, it is important to prompt participants to "think-aloud" and, when possible, to provide a justification about their sorting that provides insights about their mental models. Not all participants will spontaneously provide oral explanations during their sorting process. In that case, it is important to invite them to speak their thought process aloud while justifying card positions.

Due to the fact that this study was intended as a pilot to develop the and establish feasibility of the methodology, we did not undertake a full analysis of the data collected. Instead, we examined the data collected to assess if there would be adequate information for analysis and to establish the optimal presentation of results. The method would allow for both quantitative as well as a qualitative data analysis. The quantitative analysis may consist of transforming the final card positions into numeric values based on their relative placement. Given that not all cards had to be used in all sessions, the number of cards per session varied. For the analysis, this means that average positions of each card could be calculated. One possibility is to sort the factors into terciles, where the first third stands for high influence, the second third for moderate influence and the last third for low influence. The interview transcripts that accompanied the card-sorting data could be analyzed qualitatively using a grounded theory approach (Strauss & Corbin, 1998; Charmaz, 2006), a systematic approach for the collection and analysis of qualitative data with a focus on generating theory out of the data material. Such an analysis would require that the interviews be transcribed verbatim to be systematically analyzed.

We learned from this pilot study that it is important to pretest such card-sorting sessions to validate the method prior to officially beginning data collection. How the cards should be sorted will depend on the topic of interest. In some cases, it may be more useful to instruct participants to sort factors or concepts to predefined groups. In other cases, as with our study, the use of a relative ranking scale may be more appropriate. The flexible nature of the card-sorting technique makes it ideal to be adapted and applied in a number of different settings. Having so many possibilities is a huge advantage but also requires that the method be tested to avoid unforeseen issues. In conclusion, we find that concept mapping is a promising approach that offers particular benefit when seeking to understand unconscious mechanisms that drive human behavior, such as mental models.

5.2. Study 6: Healthcare provider mental models of the "patient zone" examined using concept mapping.

Jasmina Bogdanovic, Simone Passerini, Hugo Sax, Lauren Clack

The work presented in this chapter is currently ongoing. Preliminary results are presented and discussed.

ABSTRACT

Background. The “patient zone” was originally introduced to the field of hospital infection prevention in 2007 as a concept to guide infection prevention efforts. The patient zone, which is considered as contaminated primarily by flora of a single patient, is geographically distinguished from the healthcare zone. Infection prevention efforts should aim to prevent the transmission of microorganisms between zones. Discrepancies in healthcare provider (HCP) mental models about how the patient zone is defined may lead to lapses in infection prevention measures that may lead to patient harm.

Methods. We undertook a concept-mapping study to reveal the mental models of HCPs regarding the patient zone. A card-sorting activity and think-aloud protocol was conducted with 10 HCPs (non-experts) and 2 infection prevention experts. Using an online card-sorting tool, participants sorted 32 items into categories of “inside” or “outside” the patient zone and verbalised their thought process throughout the activity. Percentage agreement was calculated and content analysis was done on qualitative data.

Results. Three participants (25%) reported having received training on the patient zone concept and seven (58%) reported being either well- or moderately informed about the patient zone. High agreement (≥90%) was achieved for 13 of 32 items. Medium agreement (89-60%) was achieved for seven items. Low agreement (≤59%) was achieved for 12 items. Notable differences were observed between professional groups and between experts and non-experts.

Conclusions. Items for which medium-to-low agreement was observed may represent the highest potential for infection prevention lapses. Low agreement is likely related to different mental models about how the patient zone is defined. Interventions should aim to rectify these discrepancies.

BACKGROUND

The "patient zone" was originally introduced to the field of hospital infection prevention in 2007 as a concept to guide infection prevention efforts and to anchor specific indications for hand hygiene (Sax et al., 2007). Rooted in the 2006 evidence-based model for hand transmission during patient care (Pittet et al., 2006b), the patient zone is defined in the landmark "My Five Moments for Hand Hygiene" paper as follows: "The patient zone contains the patient X and his/her immediate surroundings. This typically includes the intact skin of the patient and all inanimate surfaces that are touched by or in direct physical contact with the patient such as the bed rails, bedside table, bed linen and infusion tubing and other medical equipment. It further contains surfaces frequently touched by HCWs while caring for the patient such as monitors, knobs and buttons, and other 'high frequency' touch surfaces within the patient zone (Sax et al., 2007)." The patient zone is thus considered to become quickly contaminated with patient flora and should be cleaned between patient admissions. The healthcare zone, in contrast, contains all surfaces outside the patient zone, and is considered to be contaminated with microorganisms that are foreign and potentially harmful to the patient. Two indications for hand hygiene are thus anchored upon "entry" (i.e. before touching the first surface inside the patient zone) and "exit" of the patient zone (i.e. after touching the last surface inside the patient zone and proceeding to the healthcare zone) to prevent the cross transmission of microorganisms that could harm patients between zones.

The patient zone was intended to be adaptable and transportable to any context to facilitate compliance with hand hygiene across settings. The patient zone is also at the heart of direct hand hygiene observation methods (*WHO guidelines on hand hygiene in health care*, 2009) and used by infection prevention professionals to assess and compare rates of hand hygiene across the world (Stewardson, Allegranzi, Perneger, Attar, & Pittet, 2013). It is unclear, however, the extent to which the patient zone concept is known or used by individuals who provide patient care. Observational studies have shown that infectious risk moments occur frequently as a result of behaviours that may transmit microorganisms between surfaces from the wider healthcare environment to the patient and the patient's direct environment (Sax & Clack, 2015; Clack et al., 2018b). Further, discrepancies in healthcare provider (HCP) mental models about how the patient zone is defined may lead to lapses in infection prevention measures that could result in patient harm (Sax & Clack, 2015).

We thus undertook a concept-mapping study to explore HCP mental models about the patient zone.

METHODS

Study design

Concept mapping using a card sorting technique together with verbal think-aloud protocol was chosen to explore the underlying beliefs that make up HCP mental models regarding the patient zone.

Participants

We recruited a convenience sample of clinicians who were available on the days the study was being conducted. Participants were recruited from a general medical ward and the infectious diseases department. We purposefully selected this mix of participants to include individuals trained and familiar with infection prevention, as well as individuals without specialty training in infection prevention. Data collection continued until saturation was reached.

Procedure

The card sorting and think-aloud sessions were conducted as semi-structured interviews and took place between January and February 2018. The researchers gave background information about the study and explained the procedure. Before completing the card-sorting task, each participant was instructed to provide a definition of the patient zone in his or her own words. Each participant then completed the card-sorting activity using an online-tool (https://www.optimalworkshop.com/optimalsort). Participants were provided with a standardized scenario of a two-patient bedroom on a general ward and were shown a set of cards with several items from the care environment to be sorted. The list of items to be sorted was generated based on observations from a previous study (Clack et al., 2018b). Participants were instructed to sort all the item cards into one of two pre-defined groups: "inside patient zone" or "outside patient zone". The layout of the activity is shown in Figure 18.

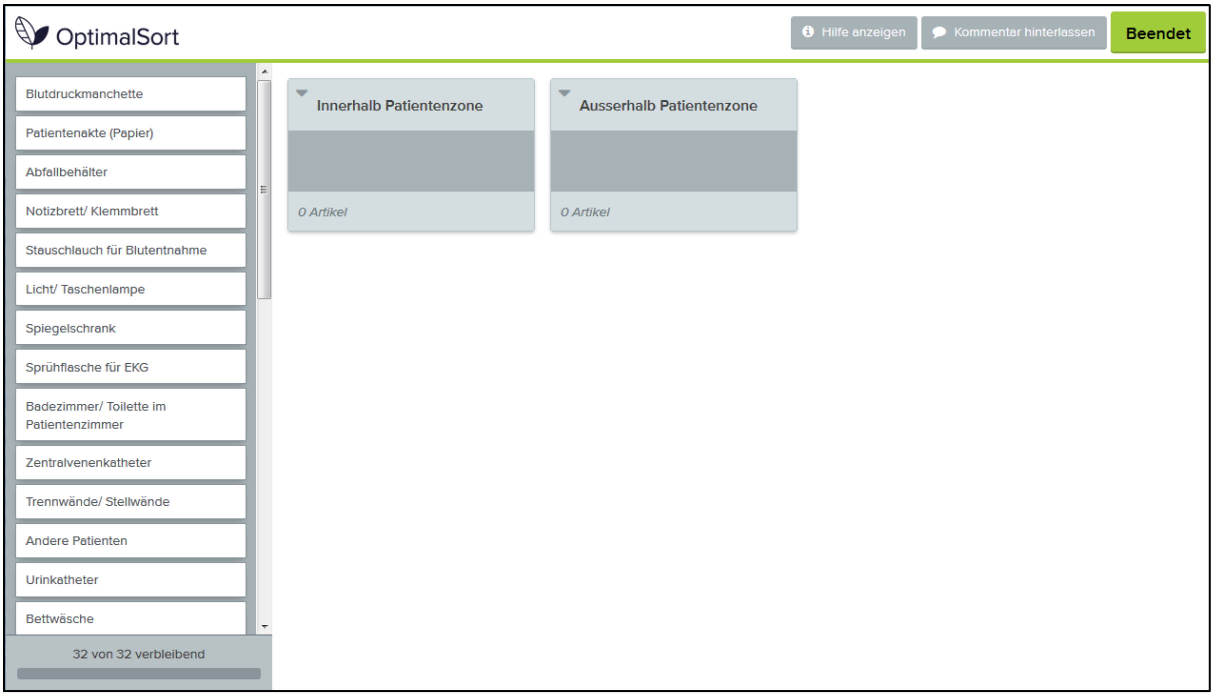

Figure 18: Layout of card-sorting activity using online tool

Participants were allowed to assign each item to only one group, and thus were required to make a decision for each item even when unsure. For the think-aloud protocol (Davey, 1983), participants were instructed to "think out loud" throughout the card-sorting task, and to verbalise their thought process, especially as to why they sorted each item as belonging in- or outside the patient zone. After the card-sorting activity, participants gave a subjective rating of their own knowledge about the patient zone concept on a five-point Likert scale. One researcher with training in psychology and familiar with the infection prevention context (JB) performed data collection. The card-sorting and think-aloud sessions were videotaped so that it was possible to attribute the spoken word from the interviews to what was happening in the card-sorting process.

Analysis

Card-sorting results were exported as raw frequency data and percentages from the online-tool. The interview material was not transcribed verbatim – instead, we performed a content analysis using an excel spreadsheet where we captured profession, participant code, category (inside vs. outside patient zone), participants' reason for assigning a certain object to one or the other category and verbatim transcribed quotes.

RESULTS

Overall, 12 interviews were conducted with 10 HCP (5 nurses, 5 physicians) without special training in infection prevention, and 2 experts (1 nurse, 1 physician) from the division of infectious diseases and hospital epidemiology. 58.3% of all participants were female. The average age was 32.25 years. Based on subjective ratings, two physicians reported having no knowledge of the patient zone concept whatsoever and the other three physicians said that they only have slight knowledge about it. Four nurses from the general medical ward reported to have an average knowledge of the patient zone concept and one nurse reported having good knowledge of it. The experts both rated their knowledge as very good. Furthermore, only three participants, including the expert, mentioned to have had a teaching regarding the patient zone or received information about it during their work at the hospital.

The quantitative results of the card sorting activity are reported in Table 10, Table 11, and Table 12. High agreement (≥90%) was achieved for 13 of 32 items. Medium agreement (89-60%) was achieved for seven items. Low agreement (≤59%) was achieved for 12 items. Both experts consistently assigned 30 of 32 items to the same group. Items for which both experts agreed were considered "expert consensus". Notable differences were observed between professional groups and between experts and non-experts, as displayed in Table 13.

Table 10: Inside patient zone: items for which medium-to-high agreement was achieved

Item	n	% Agreement	Expert consensus
Urinary Catheter	12	100	inside
Bedsheets	12	100	inside
Central Venous Catheter	12	100	inside
Bedframe	12	100	inside
Bedside table	11	92	inside
Monitor	11	92	inside
Fixed telephone in patient room	11	92	inside
Restroom / Toilet in patient room	9	75	outside
Infusion pump	8	67	inside
Curtains	8	67	mixed

Table 11: Outside patient zone: items for which medium-to-high agreement was achieved

Item	n	% Agreement	Expert consensus
Computer	12	100	outside
Healthcare provider private mobile phone	12	100	outside
Paper patient records	12	100	outside
Conductive gel bottle (for ECG)	11	92	outside
Pens	11	92	outside
Healthcare provider badge	11	92	outside
Clipboard	10	83	outside
Trolley	9	75	outside
Lamp	9	75	outside
Healthcare provider professional attire	8	67	outside

Table 12: Items for which low agreement was achieved

Item	In-/Outside	% Agreement	Expert consensus
Floor	6 each	50	outside
Stethoscope	6 each	50	outside
Tourniquet	6 each	50	outside
Medication tray	6 each	50	outside
Partition wall	6 each	50	mixed
Ultrasound	6 each	50	outside
Healthcare provider hands	7 inside	58	outside
Sink	7 inside	58	outside
Blood pressure cuff	7 inside	58	outside
Other patient	7 outside	58	outside
Mirrored Cabinet	7 outside	58	outside
Rubbish bin	7 outside	58	outside

Table 13: Sorting by professional group

	Inside Patient Zone (%)		
Item	**Experts**	**Nurses**	**Physicians**
Bedframe	**100**	**100**	**100**
Bedsheets	**100**	**100**	**100**
Urinary Catheter	**100**	**100**	**100**
Central Venous Catheter	**100**	**100**	**100**
Computer	**0**	**0**	**0**
Healthcare provider private mobile phone	**0**	**0**	**0**
Paper patient records	**0**	**0**	**0**
Bedside table	100	100	80
Fixed telephone in patient room	100	100	80
Monitor	100	100	80
Infusion pump	100	60	60
Conductive gel bottle (for ECG)	0	0	20
Healthcare provider badge	0	20	0
Pens	0	20	0
Clipboard	0	20	20
Trolley	0	20	40
Healthcare provider professional attire	0	40	40
Lamp	0	0	60
Other patient	0	40	60
Mirrored Cabinet	0	60	40
Rubbish bin	0	80	20
Floor	0	80	40
Tourniquet	0	40	80
Stethoscope	0	40	80
Medication tray	0	40	80
Ultrasound	0	40	80
Blood pressure cuff	0	60	80
Healthcare provider hands	0	60	80
Sink	0	60	80
Restroom / Toilet in patient room	0	100	80
Partition wall	50	60	40
Curtains	50	100	40

DISCUSSION

The results of this study are still undergoing analysis. Preliminary results have been presented and will be discussed in the following section.

Mental models of the patient zone

The combined approach of asking individuals to provide a definition of the patient zone and to sort items according to the patient zone allowed for triangulation of the beliefs that underlie the mental models of the HCPs who participated in this study.

Participants' explanations as to why they sorted certain items as "inside" versus "outside" the patient zone were often consistent with their given definitions of the patient zone. For example, "proximity" to the patient was frequently cited when sorting items to inside the patient zone, particularly among individuals who cited proximity (e.g. "within one meter of the patient") in their patient zone definitions. Shared items, or items that were considered to move from one patient to another, were sorted to outside the patient zone, especially by participants who defined any single patient zone as those objects that "belong to" or come only into contact with a particular patient.

In contrast, some cognitive dissonance (Festinger, 1962) was observed when participants defined the patient zone as "the patient room and all objects in it" (3 participants) then proceeded to sort items that are indeed located inside the room or that do enter the patient room, such as the floor, a stethoscope, and HCP hands, as outside of the patient zone. It became clear when multiple participants said, "It depends on the situation" that such a static definition of the patient zone was incompatible with actual patient care and participants had difficulty sorting items consequently according to this definition. Such cognitive dissonance as demonstrated by conflicting patient zone definitions and item sorting is consistent with the concept of mental models, that these may be flawed or inconsistent representations of reality (Sax & Clack, 2015).

Items with low agreement

Conceptually, items for which low agreement was achieved are those that are most likely to be involved in hygiene lapses. In this study, these included items of the physical environment such as partition walls, mirrored cabinets that are fixed to the hospital walls, and sinks in patient rooms. Such low levels of agreement were particularly driven by differences between profession groups (table xx). For example, nurses who frequently access the mirrored cabinets while providing direct patient care more frequently assigned the cabinets to inside the patient zone, whereas physicians more frequently assigned them to outside the patient zone.

Other items for which low agreement was achieved include mobile objects and medical devices that move between patients, such as the stethoscope, medication tray, and blood pressure cuff. Sorting these items into one zone was challenging for participants, given that they may transiently move between zones. The most important infection prevention implication for such items is that they must be adequately disinfected between contacts with multiple patients to prevent transmission of potentially harmful microorganisms. Interestingly hands of healthcare workers also fell under this category, which is consistent with the “My Five Moments” concept for hand hygiene between patient zones (Sax et al., 2007).

Expert ratings

The observation that the two experts participating in this study had high levels of agreement, agreeing on all but two of 32 items, suggests that it may be possible to learn and consequently apply a definition of the patient zone. Both experts defined the patient zone according to the items that surround a patient and are likely contaminated by that patient’s flora, consistent with the established definition (Sax et al., 2007). Both experts also cited the implications of the patient zone, such as the need for disinfection of items that travel between patients (items outside the patient zone.

CONCLUSIONS

The findings of this study have important implications for infection prevention and control. First, they indicate that the although the patient zone concept is established and frequently employed among infection prevention professionals, it is not a well-known concept to all frontline HCPs and significant disagreement, particularly between professional groups, exists regarding which items belong to the patient zone. This was true in a sample of 10 HCP working in a hospital with an established infection prevention and control department, ongoing infection prevention training for hospital staff, and an extensive history of infection prevention campaigns and promotion. Our qualitative analysis further revealed that HCPs had inconsistent mental models about the patient zone, which could lead to important lapses in infection prevention. Future infection prevention efforts should address such inconsistencies to limit the transmission of potentially harmful microorganisms between patients. Such efforts may take the form of education to increase individual knowledge about the patient zone and its implications, or structural modifications, for example making items in patient zone a different colour to increase awareness about the different zones. Further options for designing interventions are addressed in the discussion section 7.5, Implications.

5.3. Study 7: Video reflexive ethnography to explore healthcare provider risk perceptions.

Lauren Clack, Simone Passerini, Jasmina Bogdanovic, Hugo Sax

The work presented in this chapter is currently ongoing. Preliminary results are presented and discussed.

ABSTRACT

Introduction. Video-reflexive ethnography has been established as a useful approach for identifying the physical, social, and cognitive processes that underlie human behaviours. Within the scope of an overarching study examining the behaviours of healthcare providers (HCP) that may result in infectious patient outcomes (i.e. infection risk moments, IRM), we employ a video-reflexive approach to understanding the factors that influence HCP infection prevention and control behaviours.

Methods. Participating nurses and physicians from four wards were filmed while providing active patient care. Care films were reviewed during 30-minute individual reflexive interview sessions. Participants "thought-aloud" while viewing their care film, followed by a semi-structured interview during which participants were shown and asked to comment on potential infectious risks. Post-interview, participants completed a survey assessing the extent to which their practice had changed. Data collection and analysis were theoretically informed by the Theoretical Domains Framework (TDF) and the Consolidated Framework for Implementation Research. Interviews were transcribed verbatim, analysed deductively based on the TDF, then inductively to identify emergent insights.

Results. We conducted 40 semi-structured video-reflexive interviews (five nurses and five physicians from each ward). On average, interviews lasted 32 minutes and 15 minutes of active patient care were recorded per interview. The following domains emerged as being of high relative importance in this study (Table 17): "Environmental Context and Resources", "Knowledge", "Nature of the Behaviour", "Beliefs about Consequences", "Memory, Attention, and Decision Processes" and "Social Influences". Overall, 65% of participants completed the post-interview survey, of which the majority felt participation in this activity resulted in at least a very minor improvement in their awareness (92%) and behaviours (85%) related to infection prevention.

Discussion. A thorough understanding of the factors influencing HCP behaviours is a prerequisite to designing effective behaviour change interventions. Mapping the behavioural determinants identified in this study to corresponding behaviour change techniques can guide this process of designing effecting infection prevention strategies. The relatively high self-reported influence of study participation on infection prevention awareness and behaviours suggests that our study had high catalytic validity.

INTRODUCTION

Ethnography, an approach employed by anthropologists and other social scientists, can be defined as the scientific, in-depth study of individuals and groups (Patton, 2002). Ethnography is often conducted by spending extended periods “in the field” to observe and describe everyday behaviours taking place in their natural settings. Ethnography has been cited as a valuable approach for healthcare quality and safety improvement initiatives to understand the complex interactions and difficult-to-measure phenomena within care environments (Dixon-Woods & Bosk, 2010). Ethnography is typically conducted by trained researchers, who spend extended periods collecting data through observations, interviews, and artefacts. With the introduction of video as an ethnographic tool, researchers are now able to capture rich and complex interactions as they occur, rather than to reconstruct them from field notes. Video ethnography has recently been taken a step further by introducing a feedback element, whereby individuals are invited to reflect upon a played-back video sequence (Carroll et al., 2008) .

This technique, termed video reflexive ethnography (VRE), thus seeks to elicit the physical, social and cognitive processes that underlie human behaviour while performing a specific task. In the domain of human factors engineering, a similar technique entitled verbal protocol analysis is frequently employed whereby participants are invited to perform a task while “thinking aloud” (Stanton, Salmon, Walker, Baber, & Jenkins, 2005). This interaction is often filmed and then analysed. Similar to video-reflexive ethnography, the goal of verbal protocol analysis is to understand the cognitive processes underlying complex behaviours.

Such reflexive techniques serve multiple purposes. On one hand, they are consistent with adult learning theory, encouraging experiential, self-directed learning and inciting participants to think critically about their behaviour and thus representing a behavioural intervention in and of itself (Knowles, 1975; Davis-Beattie & de Wit, 1996). Additionally, video reflection serves as an interesting research tool, allowing investigators to understand the underlying beliefs, also known as "mental models" of healthcare workers that drive their behaviours.

The field of infection prevention is particularly suited for the use of such reflexive techniques, because human behaviour is known to play a major role in the prevention of healthcare-associated infections (Kretzer & Larson, 1998). Understanding the mental models of individual healthcare workers as they relate to infectious risks may therefore provide valuable insights to inform infection prevention initiatives (Sax & Clack, 2015).

The work presented in this manuscript was conducted within the scope of a larger study developing and applying a behavioural science paradigm to infection prevention (Clack et al., 2014; Clack et al., 2018b). The larger study specifically identified healthcare provider behaviours that may result in the transmission of microorganisms involved in healthcare-associated infections, termed infectious risk moments (IRM). The next step prior to designing interventions to address IRM is to understand the behavioural determinants that influence healthcare provider infectious risk behaviours.

The objective of the current study was to combine video reflexive ethnography together with a reflexive think-aloud task in order to understand the physical, social, and cognitive processes that influence healthcare provider behaviours 1) relevant to infection prevention in general and 2) specific to IRM behaviours.

METHODS

Setting

This study was conducted at a 900-bed, university-affiliated tertiary care hospital. The four wards participating in this study included a general medical ward, an intensive care unit, an emergency ward, and a trauma ward. These wards were purposefully selected to include a broad range of care activities and potential infectious risks.

Participants

Volunteer participants were purposefully selected according to their workplace and profession, to include 10 individuals (five nurses and five physicians) from each of the four participating study wards. Within these criteria, a convenience sample of 40 individuals was collected based on availability for filming and interviewing. Potential participants were initially informed of the study by email from the respective ward heads, then approached face-to-face by the researchers during working hours.

Theoretical Frameworks

This research was informed by two primary sensitizing frameworks. The Theoretical Domains Framework (TDF) (Cane et al., 2012) and the Consolidated Framework for Implementation Research (CFIR) (Damschroder et al., 2009) informed data collection to ensure that a broad range of factors at both the individual and organisational levels potentially relevant to infectious risk behaviours were explored. The TDF was further used as a coding framework during the inductive analysis of interview transcripts.

Data collection

Care filming. Periods of active patient care were filmed in approximately 10-15 minute sequences using a GoPro chest-mounted camera worn by one researcher to ensure that the participating HCP was always within the field of view.

Reflexive interview. Following the patient care filming session, individual HCPs participated in a 30-minute reflective interview. The interview began with the participant viewing their care film and reflexively “thinking-aloud” while viewing the film. Participants were then shown and asked to comment on 2-3 potential infectious risks identified during the care film. The session finished with a reflexive interview based on the semi-structured guide.

Interview guide. The semi-structured interview guide (**Table 14**) was developed based on TDF and CFIR constructs, and was pilot tested with three HCPs from a non-participating ward prior to beginning this study. Adjustments to the guide were made accordingly.

Debriefings. Immediately following each interview, a short debriefing including a description of the interview and any main topics addressed during the interview was noted by one researcher. These debriefing texts were added to the beginning of each interview transcript and included in analysis.

Analysis

Transcription: All interviews were transcribed verbatim, and checked for accuracy.

Deductive analysis: During a first stage of analysis, all interviews were deductively coded using the TDF as a coding framework and coding at the domain level. The TDF-based coding framework was slightly adapted to include one code to capture all utterances related to reflection about the video-reflexive session, and another code to capture specific barriers, facilitators, and suggestions. The code relating to barriers, facilitators, and suggestions was systematically double-coded in addition to a TDF code. Coding was conducted by two independent researchers for 100% of transcripts and any discrepancies in coding between researchers were resolved through consensus discussions. MAXQDA quantitative data analysis software was used for coding and managing data analysis ("MAXQDA, software for qualitative data analysis," 2018).

Inductive thematic analysis: In a second step, inductive thematic analyses were conducted, during which data that had been coded into TDF domains were re-examined and sorted thematically to identify emerging insights. Theme labels were assigned to clusters of similar data and these labels were discussed until group consensus was achieved. Inductive analyses were conducted at the ward level.

Cross-case analysis. During cross-case analysis, stacked matrices (Miles & Huberman, 1994) were created to visualise how themes varied across the four study wards.

Post-participation survey

To assess the catalytic validity of our video-reflexive approach (Bailey, 2010), all participants were invited approximately two weeks after the reflexive interview to complete a short, paper-based survey (**Table 15**). The survey included two questions regarding the influence of study participation on awareness and behaviour related to infectious risks.

Ethics

The Cantonal Ethics Committee of Zurich has determined that this project falls under the realm of quality improvement and has formally issued Ethics Waiver KEK-StV-Nr 06/13. Written informed consent was obtained from all healthcare workers and concerned patients prior to filming. Participation by healthcare workers and filmed patients was voluntary and they were free to drop out or to stop filming at any time without providing justification, although this never occurred in our study.

Table 14: Semi-structured interview guide

Part 1: Think aloud, prompting questions

- What comes to your mind as you are watching?
- Does anything stand out to you?
- Repeat participant utterances as probing questions (e.g. “oops”?)

Part 2: Potential infectious risks

- We would like to show you a scene, where we think there may be a potential infectious risk (show scene). What comes to mind when you watch?
- Do you think this may be clinically relevant?
- Would could be potential outcomes (of the observed behaviour)?
- To what extent do physical or resource factors influence (the observed behaviour)?
- To what extent do social influences affect (the observed behaviour)?
- Are there any professional expectations related to (…)?
- How difficult or easy is it for you to (…)?
- How did you learn about (…)?
- Are you aware of any guidelines or evidence regarding (the behaviour)?
- How did you decide to (…)?
- Is (…) something you usually do?
- How difficult or easy is it for you to (…)?

Part 3: General questions and reflection about the process

- Is there anything that we have not observed in the film that facilitates or hinders your infection prevention behaviour?
- Is there anything we have not discussed, that you would like to add?
- Do you have any suggestions, about how we could make infection prevention easier?
- How was it for you to participate in this exercise?
- Do you think being filmed had any influence on your behaviour? If so, how?

Table 15: Post-participation follow-up survey

1. **To what extent, if at all, has your awareness about infectious risks changed since participating in this study? Please explain.** (0, not at all; 1, very minor change; 2, minor change; 3, medium change; 4, strong change; 5 very strong change)
2. **To what extent, if at all, has your infection prevention behaviour changed since participating in this study? Please explain**. (0, not at all; 1, very minor change; 2, minor change; 3, medium change; 4, strong change; 5 very strong change)
3. **Would you recommend a colleague to participate in this study?** (yes, no)

RESULTS

Overall, 40 semi-structured interviews were conducted with five nurses and five physicians from each of the four participating study wards. Of the nurses interviewed, 11 of 20 were female. Of the physicians interviewed, 6 of 20 were female. A total of 10 hours of direct patient care film were recorded, equating to an average of 15 minutes per individual interviewed. Reflexive interviews lasted, on average, 32 minutes (range, 21-46 minutes).

Deductive TDF coding

A total of 2’431 utterances were coded according to the TDF-based coding framework. **Table 16** shows an overview of our adapted TDF-based coding framework and example quotations. Apart from “Barriers/Facilitators/Suggestions” (n=481), which was systematically used as a double code to keep track of specific barriers, facilitators, and suggestions and “Reflection of VRE session” (n=155), which was used to assess the validity of the video-reflexive approach, the following domains were coded the most frequently across all four wards: “environmental context and resources” (n=416), “knowledge” (n=276), “Nature of the behaviour” (n=276), “Beliefs about consequences” (n=243), and “Memory, attention and decision processes” (n=154). Together, these five domains accounted for 74% of coded material. The frequency of coded utterances per domain is shown in **Table 17**.

Table 16: Adapted Coding Framework and example quotes

Domain (definition)	
1. Knowledge (An awareness of the existence of something)	*“Though, another point is that I do not know exactly when or when not to wear gloves. I mean, I know it is for every patient contact. But what does ‘every patient contact’ mean? When do I have to change them?”*
2. Skills (An ability or proficiency acquired through practice)	*“You have to develop a certain routine. And surely, you know after a while. I also had a long time of training. After a while then you know how to handle certain processes and care tasks.”*
3. Social/Professional Role and Identity (A coherent set of behaviours and displayed personal qualities of an individual in a social or work setting)	*“Actually one does not often change (professional) clothes when working in the ICU, for the reason that one usually does’t come into contact with the patient himself, our clothing doesn’t come into contact, at least us physicians. We almost never do mobilisation of the patient.”*
4. Beliefs about Capabilities (Acceptance of the truth, reality, or validity about an ability, talent, or facility that a person can put to constructive use)	*“But at one point, when things get hectic and you need something out of the cupboard, then you utterly have no time to always take off the gloves, disinfect (your hands) and only then take something out. This is simply not feasible.”*
5. Optimism (The confidence that things will happen for the best or that desired goals will be attained)	*“It could perhaps [lead to an infection]. I hope not, and I hope that the ultrasound wasn’t used on a patient with MRSA or MRGN, but theoretically it could.”*
6. Beliefs about Consequences (Acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation)	*“I was aware that my gloves were not clean. I was aware of it, but the gloves are not for patient protection, they are for my protection. I was aware of it. I was also aware that this wound treatment, ehm, this patient, that she, ehm, got antibiotics in the first place.”*
7. Reinforcement (Increasing the probability of a response by arranging a dependent relationship, or contingency, between the response and a given stimulus)	*“So maybe one is not aware enough, maybe it is because there are too few consequences, if something from the blood drips into the bed, then this is displeasing but it is not…it has no huge…does not lead to a punishment or so.”*
8. Intentions (A conscious decision to perform a behaviour or a resolve to act in a certain way)	*“If I were in doubt, I would have made the effort and take the time to consider, to do [glove change] in that time.”*
9. Goals (Mental representations of outcomes or end states that an individual wants to achieve)	*“I think we owe this to the patients, that we stick to that, with the goal to optimise and minimise hospital infections. This is our mandate, and we have to continue working on it.”*

10. Memory, Attention and Decision Processes (The ability to retain information, focus selectively on aspects of the environment and choose between two or more alternatives)	*“Sometimes it is difficult to comply with the guidelines, regarding the procedures, because in an ICU you have these alarms all the time and somehow you have to react and then it happens to forget all the [infection prevention] things amidst all that.”*
11. Environmental Context and Resources (Any circumstance of a person's situation or environment that discourages or encourages the development of skills and abilities, independence, social competence, and adaptive behaviour)	*“Apart from that, it is very important that there is enough disinfectant at well accessible spots, so that you do not have to go and search for it. Rather, that you can disinfect your hands on the way.”*
12. Social influences Social pressure (Those interpersonal processes that can cause individuals to change their thoughts, feelings, or behaviours)	*“Now I have taken off my wedding ring and my watch, what I always do. I do it because it gets pointed out to me. Otherwise, I would not have done it.”*
13. Emotion (A complex reaction pattern, involving experiential, behavioural, and physiological elements, by which the individual attempts to deal with a personally significant matter or event)	*“I have to say that when I put on gloves because the patient stinks, is disgusting, and unwashed, then I put them on primarily because of myself. I have to say, that it’s not as if the patient who doesn’t wash himself has more infectious diseases that could be transmitted. So I guess it’s more about self-protection.”*
14. Behavioural Regulation (Anything aimed at managing or changing objectively observed or measured actions)	*Before I touch the Infusion/ transfusion, I think, I should disinfect my hands. What I did was, I don’t know if you can see this here [in the video], is this non-touch technique. Taking care to always have enough distance to the connections, to surely not touch it.*
15. Nature of the behaviour (TDFv1) (Characteristics of the behaviour or the larger care task that affect the way it is performed)	*“Also here, again, at the head…I start at the top, hygienically, it is cleaner at the upper area. Thorax, the legs at the end and then I go to the next disinfection dispenser. This is always my routine.”*
17. Reflection of VRE session* (Becoming aware of one’s own behaviour while watching themselves during care video, or acknowledging change in behaviour because of filming)	*“I usually wash my hands after examination and clean the stethoscope. The next step is to sit down at the computer. Then I get called by the nurses to see the next patient. I get up, take my cleaned stethoscope, usually hang it around my neck as you can see it here [in the video] and go in [to the patient room]. But now when I look at it, it wouldn’t be too much to also disinfect my hands again after entering the patient room and before shaking the patients’ hand.”*
16. Barrier/Facilitator/Suggestion* (Anything that was mentioned as supporting or hindering infection prevention, as well as solutions mentioned)	*“Thanks to the fact that we have motion sensors and we don’t have to touch to open the doors, this already helps a lot.”*

Table 16 Note: Our coding framework was based on the Theoretical Domains Framework (TDF) version 2 (Cane et al., 2012), with the exception of the domain, “Nature of the behaviour”, which came from the original TDF version 1 (Michie et al., 2005). Domains indicated with an * were added to the framework to capture specific items of interest to this study.

Table 17: Frequency of coded utterances per domain

TDF Domain	E-SUED	B-HOF	NOTF	SCHOCK
1. Knowledge	**62**	47	**74**	**93**
2. Skills	5	8	3	8
3. Social/Professional Role and Identity	2	11	17	20
4. Beliefs about Capability	2	22	10	23
5. Optimism	0	0	3	0
6. Beliefs about Consequences	**71**	**72**	59	41
7. Reinforcement	0	0	0	2
8. Intentions	19	30	10	13
9. Goals	0	3	1	1
10. Memory, Attention and Decision Processes	14	**52**	38	50
11. Environmental Context and Resources	60	**122**	**92**	**142**
12. Social influences	27	17	27	28
13. Emotion	22	9	22	10
14. Behavioural Regulation	12	25	24	26
15. Nature of the behaviours	**65**	46	**77**	**56**
16. Reflection of VRE session*	47	33	40	35
17. Barrier/Facilitator/Suggestions*	85	123	101	172

Legend Table 17: The three most frequently coded domains per ward setting are shown in bold. Domains indicated with an *, were excluded from frequency analysis.

Inductive thematic analysis

Overall, 60 themes emerged during inductive thematic analysis, as presented in **Table 19**. A narrative description of selected themes judge to be of high relative importance are presented in the following sections.

Relative importance of domains. Based on the predefined criteria of (1) coding frequency and (2) elaboration of themes, the following domains emerged as being of high relative importance in this study (**Table 18**): “Environmental Context and Resources”, “Knowledge”, “Nature of the Behaviour”, “Beliefs about Consequences”, “Memory, Attention, and Decision Processes” and “Social Influences”. Of note, domains 16 and 17, not part of the TDF framework, were excluded from this analysis.

Table 18: Criteria to assess relative domain importance

TDF Domain	Coding frequency	Number of themes
11. Environmental Context and Resources	**416**	**7**
1. Knowledge	**276**	**5**
15. Nature of the behaviours	**244**	**5**
6. Beliefs about Consequences	**243**	**6**

10. Memory, Attention and decision Processes	**154**	**6**
12. Social influences	**99**	**6**
14. Behavioural Regulation	87	4
8. Intentions	72	2
13. Emotion	63	4
4. Beliefs about Capability	57	2
3. Social/Professional Role and Identity	50	4
2. Skills	24	4
9. Goals	5	1
5. Optimism	3	1
7. Reinforcement	2	1

Table 19: Themes inductively identified per domain

Domain	Themes
1. Knowledge	- Knowledge of rules, guidelines, patient zone - Knowledge of hygiene status - Knowledge of microbiology, transmission dynamics - Education - Knowledge based on empirical observations
2. Skills	- IPC during professional (e.g. nursing or medical) training - Lack of training - Professional experience - Skills
3. Social/Professional Role and Identity	- Professional role - Ambiguity about professional responsibilities - Professional responsibility to act as role model to junior staff - Professional image of IPC
4. Beliefs about Capabilities	- Psychological capability of speaking up about hygiene lapses - Compliance is not feasible given time constraints
5. Optimism	- Hope no negative outcome will occur
6. Beliefs about Consequences	- **Beliefs about likelihood of transmission** - **Belief about likelihood of patient infection** - **Belief in efficacy of preventative measure** - **Self-protection** - **Beliefs about consequences biased by patient appearance** - **Beliefs about consequences based on empiric observation**
7. Reinforcement	- No traceable consequences of unsafe behaviour
8. Intentions	- Intention to comply with IPC - Motivation
9. Goals	- Goal to avoid negative patient outcomes
10. Memory, Attention and Decision Processes	- Awareness of contamination - Awareness of own behaviour - Decision to respect IPC or not - Forgetting - Distraction - Fatigue
11. Environmental Context and Resources	- Lack of time - Staffing - Availability and placement of materials - Availability and placement of waste disposal - Contaminated mobile objects - Salient or urgent care situations - Physical ergonomics of gloves
12. Social influences Social pressure	- National culture - Social norms vary in different wards - Informal rules - Positive and negative role models - Patient perception - Teamwork
13. Emotion	- Stress - Disgust - Subjective feelings of clean/dirty - Anxiety
14. Behavioural Regulation	- Self-monitoring - Excuses for unsafe behaviour - Work-around - Conscious rule violations
15. Nature of the behaviour (TDFv1)	- Conscious/unconscious behaviours - Routine/standard vs. non-routine task - Sterile vs. non-sterile task - Cues built into task workflow - Preparation
17. Reflection of VRE session	- Insights - Hawthorne effects

In the following section, domains that emerged as highly relevant to infectious risk behaviours are discussed.

Environmental Context and Resources

The theoretical domains framework defines environmental context and resources as person's individual circumstances on a physical and organisational level that discourages or encourages a person's development of skills, abilities and behaviour. Within this domain, elements of the physical environment (e.g. space, physical ergonomics of devices), organisational factors (e.g. availability and placement of materials, staffing) and resources (e.g. lack of time), were found to influence infection prevention behaviours.

Lack of physical space to perform procedures was frequently cited as a barrier. This, for example, caused individuals to come into contact with several surfaces, often unintentionally, resulting in potential transmission.

"It is also the space for the amount of people that we are. The space you have is just…Sometimes you have 15 people around you. You always have to somehow wind through this. […] and everything is so narrow." (trauma ward)

The availability and placement of objects was mentioned both, as a facilitator but also as barrier. This was noted as an important factor particularly for hand hygiene and for the appropriate disposal of waste.

"What I notice and what is very important and good, is that the (hand rub) dispensers are easy to access and they are at many locations, […] If it is there [a dispenser] then you do it [hand hygiene], if it is not there, you won't do it." (trauma ward)

"I notice something else. Everyone in the trauma ward knows that the waste is located directly under the list of telephone numbers. We have noticed this long ago but somehow

nothing gets changed. So if you are on the phone or have to look up something on the list then you are about 20 cm away from the waste. […] I think it is because there is no right location for the waste, so that it is not in the way."(emergency ward)

Lack of time also emerged as an important theme. For example, HCPs said that the indications for hand hygiene are unrealistic given time constraints and high workload.

"You try to disinfect your hands but of course, it is always the time factor. It is additional work you have to carry out. […] I think that often, when it does not get done properly, it is due to stress, it is the time factor, I think it is rather that."(intensive care)

This finding was further exacerbated when there was a lack of staff.

"During night time we are not many. Once they are here, six, seven, I don't know how many people and suddenly there are only four in the night. Then you can only run from one patient to the other[…]" (emergency ward).

Salient or urgent care situations meant time pressure, but also cause infection prevention to be viewed as low priority relative to the care task at hand.

"That you are not fully aware of the importance of hygiene. That you say, aha, hygiene, it is not about hygiene now. At the moment it is about saving the patients' life. They are often very ill." (trauma ward).

Other themes within this domain related to the physical ergonomics of the gloves. Whereas local guidelines indicate that one should perform hand hygiene prior to donning gloves, this was mentioned several times as nearly impossible to don gloves on wet hands. Given this challenge, HCPs often opted to skip hand hygiene altogether.

"[…] When you put on gloves, and you do hand hygiene before, you almost can not get in the gloves anymore, and then there are a lot of people they don't do hand hygiene before anymore." (medical ward)

Knowledge

The theoretical domains framework defines knowledge as an awareness of the existence of something. The themes that were brought up by the video-reflexive ethnography are knowledge about rules and guidelines, knowledge about the hygiene status of objects, knowledge about microbiology and transmission dynamics, knowledge about evidence to support the practices and education in general.

The results show that there is certainty as well as uncertainty regarding HCP's knowledge of existing guidelines and rules (e.g. wearing and changing gloves, disinfecting hands, hand hygiene technique, cleaning equipment, etc.). Apparently, HCPs are not unaware of the existence of these guidelines, but they are often unaware of the exact content and specific details of the guidelines.

"Though, another point is that I do not know exactly when to wear gloves and when not. I mean, I know it is for every patient contact. But what does ' for every patient contact' really mean? When do I have to change them?" (trauma ward)

"Wearing gloves is not a substitute for doing hand hygiene." (emergency ward)

The disinfection status of objects was ambiguous as well. Interviewees reported mainly that they assume and expect objects to be cleaned after use but very often, they were not able to say that they are completely sure about it.

"Ultrasound. I scrupulously take care to always clean it before and after use. […]but it happens often that I find the ultrasound probe smudged with gel, and I know, it surely has not been cleaned." (intensive care)

Some participants also showed knowledge about microbiology and transmission dynamics. They addressed the potential risk of germ transmission when touching first themselves (e.g. face, hair, etc.), objects from the environment (e.g. phone or pens), equipment (e.g.

stethoscope, ultrasound device, etc.) and then the patient without disinfecting hands in between.

"I don't know how hygienic this was now. But I think it is legitimate, depending on if the plug was hanging in the air, resting on the patient or lying on the floor. And now, we take off to the intensive care unit together with all the germs (laughs)." (trauma ward)

Even though they were not asked about their knowledge about scientific evidence to support the infection prevention practices, mostly physicians referred to either their existing or their missing knowledge about studies and the need to have information to support the guidelines and rules at the hospital.

"I don't even know if hand hygiene reduces the infection rate. Are there any studies about this?" (trauma unit)

Education seems to be an important element to enable an adequate implementation of infection prevention practices. Yet, participants mentioned that there is still need for more teaching, training, and especially feedback to their daily work.

"I think that there is not enough time dedicated to teach the medical interns how to get dressed or even more important how to take off their clothing again after leaving the patient bunk." (emergency ward)

Beliefs about consequences

Beliefs about consequences can be described as the acceptance of the truth, reality, or validity about outcomes of a behaviour in a given situation. The main themes that emerged within this domain included beliefs about the likelihood of germ transmission and patient infection, beliefs about consequences based on empiric observation, belief in the efficacy of preventive measures, beliefs about consequences biased by patient appearance and self-protective behaviour.

When asked about the risks associated with specific IRM, participants reveal their belief about a high likelihood of germ transmission between HCPs and patients (e.g. HCP touches own hair, then patient), patient to patient (e.g. not disinfecting stethoscope between patients) and environment to patient (e.g. germs on curtains).

"I think that curtains are surely a source. I was already pointed out to that problem, that I should be careful to first take off and throw away the gloves while in the patient bunk, then disinfect inside the bunk and then open the curtains widely, so that I do not get in contact with them when leaving the bunk. I think there is a risk." (emergency ward)

Although, participants appreciate the likelihood of transmission, their answers vary regarding the estimation of the likelihood of patient infection. Some see a potential risk when touching the patients feet and afterwards examine upper parts of the patients' body. Others only see a potential infection risk if open wounds are involved.

"This was a head laceration. Well, however, at the head, the infection risk is per se marginal." (trauma ward)

Yet others do not see a potential risk at all. This belief was often based on their own empirical observation and their personal experience with hospital infections.

"Not really, to be honest, from all risks of germs […] these things are a bit overrated. It is more likely, that the patient catches something another way, gets the infection. Especially, a wound infection – I have never seen a wound infection in a patient at least not in our department, that came from the outside. If so, then it came from the inside (points at the chest), from a pneumonia and then it started, but NEVER from the outside." (medical ward)

Participants do believe in the efficacy of preventive measures. Preventive measures that are integrated in the environment (e.g. automatic doors) facilitate infection prevention. Participants even see side effects resulting from infection prevention measures. Isolation precautions, for example, may raise the HCPs awareness and lead to a more cautious behaviour, but may also have an unintended consequence that these patients are visited less frequently.

"Maybe also because such isolations can be very extensive, then most of the people do not even feel like getting changed. That is why the number of people who enter an isolation is lower. Probably, this leads to the effect that we carry out less and carry in less [germ transmission]. Apart from that, I do not know if these isolation measures are more efficient than the standard hygienic measures." (trauma ward)

Patients' status and appearance (e.g. severe diseases) also have an influence on the HCP belief about consequences regarding the risk of infection. This also results in an adapted behaviour because the HCPs think that they should be more careful with such patients.

"If they are immunosuppressed? I think it should not make a difference but I also think when I have something like that [immunosuppressed patient], then I am even more…then I take more care. […] or I wear a surgical mask even if I would not have to." (emergency ward)

Another important hygiene topic is HCP's self-protective behaviour. Participants mentioned mostly that they protect themselves by wearing gloves. They put on gloves according to the hospital guidelines (i.e. when contact with body fluids) but also when the patients' appearance leads them to do so (e.g. patient looks not tidy).

"I mean, sure, the gloves are here for my own protection, self-protection but also to not carry around too much [germ transmission]." (medical ward)

Post-participation survey

Overall, 65% (n=26, 13 nurses, 13 physicians) of participants completed the post-interview survey, of which the majority felt participation in this activity resulted in at least a very minor improvement in their awareness (92%, n=24) and behaviours (85%, n=22) related to infection prevention. All but two of the participants who completed the survey (92%, n=24) indicated that they would recommend participating in this study to a colleague.

DISCUSSION

This video-reflexive study based on interviews with 40 HCP from four care settings revealed that elements of the environmental context followed by HCP knowledge and beliefs about consequences are likely to be the most important influencers of HCP infection prevention behaviours. Importantly, barriers in the physical and organisational environment such as lack of materials and time were hindrances to performing infection prevention activities, even among individuals who displayed adequate infection prevention knowledge. Missing or inaccurate knowledge was also a major barrier, where this concerned gaps in knowledge about infection prevention in general, as well as lack of contextual knowledge about the contamination status of objects and the environment. Regarding beliefs about consequences, HCPs consistently recognized the potential for transmission of microorganisms as a result of unsafe behaviours, yet were less convinced about the likelihood of patient infection. In contrast, belief that infection prevention measures, such as hand hygiene, are effective in prevention patient infection was a facilitator.

While the primary aim of our study was to understand the factors that influence infection prevention behaviours, it came to our attention that our video-reflexive method, which actively involved HCPs in a reflexive process, may actually be an intervention in itself. Our post-participation survey confirmed this idea, revealing that a majority of participants felt that participation in the video-reflexive ethnography resulted in at least a very minor improvement in their awareness (92%) and behaviours (85%). This finding suggests that our study had high catalytic validity (Bailey, 2010).

Our finding that barriers in the physical environment inhibit infection prevention behaviours, even among HCP with adequate knowledge, is consistent with findings from the field of health psychology. Whereas sufficient knowledge may lead to positive attitude formation and the intention to perform a behaviour, barriers in the environmental context that limit the individual's capability to perform the behaviour (i.e. self-efficacy) mean that adequate knowledge alone is insufficient to displaying safe infection prevention behaviour. This phenomenon, where intentions fail to translate into actioned behaviours, has been labelled the "intention-behaviour gap" (Sniehotta, Scholz, & Schwarzer, 2005). Understanding of this phenomenon may help to understand why interventions that focus uniquely on education and guideline dissemination to increase knowledge often fail to result in sustained improvement in infection prevention behaviours (Larson, Quiros, & Lin, 2007). Based on these findings, intervention approaches that improve self-efficacy, such as environmental restructuring and provision of adequate resources, are more "theoretically coherent" with our identified barriers and enablers, and should therefore be prioritised over educational interventions (Michie et al., 2011).

The results of this study should be interpreted in light of some limitations. First, the presence of observers and the fact of being filmed may have introduced a Hawthorne effect, causing participants to alter their natural behaviour (Parsons, 1974). While some of our interviewees did note that being filmed made them nervous or more aware of their infection prevention behaviour initially, most expressed that this effect wore off with time, or that they were not affected by filming at all. Further, as the aim of our study was to understand rather than quantify behaviour, such an observer effect should not have a major impact on our conclusions. Further, although it was explicitly communicated that the goal of this study was to understand and to support HCPs in their infection prevention efforts, some participants may have been affected by a social desirability bias and withheld information that they esteemed undesirable during the semi-structured interviews (Fisher, 1993). Finally, the broad nature of this inquiry, which sought to understand the comprehensive range of behavioural determinants of an extensive collection of infectious risk behaviours, may have prevented more behaviourally specific conclusions. Nevertheless, important conclusions could be drawn from this broad inquiry, and these insights may guide more behaviourally specific inquiries in the future. Despite these limitations, this study has several strengths, including extensive data collection with multiple professional groups from multiple care settings, followed by a rigorous data analysis with both inductive and iterative approaches to allow new themes to emerge.

In conclusion, understanding the factors that influence HCP infection prevention behaviours is paramount to designing effective behaviour change interventions. This video-reflexive study identified several physical, social, and cognitive factors that influence HCP infectious risk behaviours. The barriers and enablers identified in this study include yet go beyond HCP knowledge, which is the primary focus of many traditional infection prevention efforts. The primary barriers to infection prevention behaviours found in this study were related to the environmental context and lack of adequate resources, suggesting that environmental restructuring approaches should be prioritised. These findings have important implications for designing and implementing theoretically coherent behaviour change interventions.

6. Chapter 6: Systematic review of behavioural determinants

The following chapter complements the previous empirical studies on behavioural determinants with a systematic literature review. The chapter presented here includes the preliminary results of a systematic review of published qualitative studies that used exploratory methods to identify barriers and enablers to healthcare provider compliance with established infection prevention guidelines.

6.1. Study 8: Behavioural determinants of healthcare provider compliance with infection prevention guidelines: A systematic literature review.

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The work presented in this chapter is currently ongoing. Preliminary results are presented and discussed.

ABSTRACT

Introduction. Despite advances in the field of hospital infection prevention, rates of healthcare associated-infection (HAI) remain in the range of 10% and healthcare provider (HCP) compliance with prevention measures remains low. We undertook a systematic review of qualitative published literature to identify HCPs' reported barriers and enablers to compliance with infection prevention guidelines.

Methods. We searched (August 2017) Medline, Embase, Psychinfo, and the Cochrane Central Register of Controlled Trials. Studies were included that used qualitative methods to explore HCPs' reported barriers and enablers to compliance with infection prevention guidelines. Reported barriers and enablers were extracted from included studies as raw data (direct quotations) or author interpretation. Identified barriers/enablers were deductively coded using the Theoretical Domains Framework (TDF). Inductive thematic analyses were conducted to identify relevant themes. Relative domain importance was assessed based on (1) frequency and (2) elaboration of themes.

Results. We included 31 studies examining compliance with the following guidelines: standard and isolation precautions (e.g. hand hygiene, glove use, isolation precautions, vaccination) and HAI-specific prevention measures. We identified 368 barriers/enablers. The TDF domains judged to be of relative importance included: "social influences" (n=48, 13 themes) [e.g. patient influence, role modelling], "environmental context and resources" (n=61, 16 themes) [e.g. lack of time, ease of access to materials], and "social/professional role and identity" (n=29, 12 themes) [e.g. ambiguity about professional responsibilities].

Discussion. Whereas many infection prevention efforts focus primarily on training and education to increase HCP knowledge and improve practise, our results suggest that other important determinants may be overlooked. Our findings have important implications for guiding the design of future initiatives to address the most prevalent barriers and enablers.

INTRODUCTION

Despite advances in the field of hospital infection prevention, overall rates of healthcare associated-infection (HAI) remain in the range of 10% (*Report on the Burden of Endemic Health Care-Associated Infection Wordwide*, 2011). Furthermore, the preventable proportion of such infections remains high, with estimates over the past decades suggesting that up to 65-70% of HAI may be prevented through the systematic application of evidence-based guidelines (Harbarth et al., 2003; Umscheid et al., 2011). Despite the demonstrated effectiveness of many evidence-based practices to reduce transmission of pathogens and lower infection rates, healthcare provider (HCP) compliance with basic infection prevention and control (IPC) measures remains largely suboptimal (Larson & Kretzer, 1995; Weber et al., 2007; Gammon et al., 2008).

Evidence from the field of behavioural psychology suggests that interventions designed with theoretical justification are more effective in changing behaviour (Abraham, Kelly, West, & Michie, 2009). Understanding *behavioural determinants*, which we define as any of the wide range of mechanisms that are involved in helping or hindering individual behaviour is critical to understanding the levers at our disposal for designing behaviour change interventions. Behavioural determinants that influence individual behaviour may be *internal* - including both psychological and physical factors of the individual (e.g. knowledge about prevention measures and motivation to comply with them) - or in the *external* environment (e.g. social pressure from colleagues, placement of handrub dispensers in the work setting, physical design of catheter insertion kits) (Michie et al., 2014a). The Theoretical Domains Framework (TDF) is an integrative theoretical framework that synthesised theoretical constructs from several published behaviour change theories into 14 overarching domains (Michie et al., 2005; Cane et al., 2012). The goal of the TDF is to provide an overview of the range of constructs relevant to behaviour change and to guide behaviour change initiatives. It has also been cited as a useful framework to guide secondary data analysis.

Understanding the nature and mechanisms of behaviour change is a critical starting point for designing effective interventions (Michie et al., 2014a), particularly in the field of IPC, where improving quality of care relies profoundly on HCP behaviour (Pittet, 2004; Sax & Clack, 2015). We therefore undertook a systematic review of published qualitative literature to address the following question: **What are the behavioural determinants (i.e. barriers and enablers) that influence healthcare provider compliance with infection prevention guidelines**? To identify a broad range of behavioural determinants, the current review focused on studies using qualitative, exploratory research techniques to detect barriers and enablers to guideline compliance.

Objective formulated according to PICOS (Participants, interventions, comparisons, outcomes, and study designs)(Liberati et al., 2009): To identify barriers and enablers of healthcare provider compliance with infection prevention guidelines, we reviewed qualitative studies that reported factors that affect healthcare provider compliance with infection prevention guidelines in acute care settings.

METHODS

Search strategy

This review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) recommendations (Liberati et al., 2009). We searched Medline, Embase, PsychInfo and the Cochrane Central Register of Controlled Trials (CENTRAL) for scientific literature published in English, French, or German between 1. January 1995 and 11. August 2017. The search strategy was established in collaboration with a librarian experienced in systematic reviews and included a combination of keywords and subject headings related to each of the following topics: infection prevention, practice guidelines, healthcare providers, healthcare setting, and behaviour (**Annex 1**). The reference list of retrieved studies was also searched by hand to identify further articles of interest.

Inclusion criteria

We included qualitative research studies that examined factors observed or self-reported to have an impact on healthcare provider (HCP) (e.g. nurse, physician) compliance with IPC guidelines in acute healthcare settings.

Exclusion criteria

Because behaviour is context-dependant, we focused specifically on acute care settings and consequently excluded studies that were set in dental, ambulatory, surgical, nursing home, and long-term care and rehabilitation settings, as well as studies that exclusively considered the behaviour of students, cleaning staff, patients or family members. As the focus of this review is care provider compliance with guidelines that prevent patient infection, we further excluded studies dealing uniquely with occupational hazards for healthcare providers.

Study selection

Title and Abstract Screening. The titles and abstracts of all articles identified by our search strategy were screened by at least two independent reviewers (LC, JB, SP) for relevance. Any discrepancies were resolved by consensus between the two involved reviewers, and a third was consulted if necessary.

Full text review. The full text of articles deemed relevant during title and abstract screening (and for which full text could be obtained) were assessed for eligibility by an additional reviewer during full text review. Any articles not meeting eligibility requirements or for which full text could not be obtained were excluded at this point.

Data extraction and quality appraisal

Data extraction. We developed a data extraction sheet to collect relevant study information from each included article, including: (1) characteristics of study participants (healthcare provider profession); (2) study setting (type of hospital(s), ward speciality, number of beds, country); (3) infection prevention guideline with which compliance was assessed; (4) behavioural determinants examined; (5) study methods (including study design, data collection and analysis); and (6) relevant results (identified barriers and enablers to compliance). Qualitative results (6) were extracted as both raw data (i.e. direct quotes from study participants) and author interpretations. Our data extraction sheet was pilot-tested on ten randomly selected studies by three independent reviewers (LC, JB, TM), and refined accordingly.

Single reviewers (LC, JB, AW, SP) completed data extraction of all eligible studies. A second reviewer independently controlled a 10% subset of data extracted from included articles.

Data analysis

All included studies were grouped according to the topic of the infection prevention guideline considered in the study, namely those that considered: (1) *standard and isolation precautions*; and (2) *HAI-specific infection prevention measures*. We employed the Theoretical Domains Framework version 2 (TDFv2) as a coding framework to deductively code all identified barriers and enablers from included studies. For clarity, any mention of "domains" henceforth in this manuscript refers to the TDFv2 domains. Each identified barrier or enabler could be coded with a maximum of two TDF domains. A single reviewer conducted the coding (LC) and a subset of 15% of studies was additionally coded by a second reviewer (FL). Inductive thematic analysis were then conducted to identify relevant themes, which are reported in this manuscript. Domains were judged to be of high relative importance and selected to be discussed in this manuscript based on two criteria: (1) frequency, how often were barriers and enablers cited within the domain; and (2) elaboration, how many themes emerged within the domain.

RESULTS

Our search strategy and reference list search identified 2065 articles, of which 31 met eligibility and criteria and were included in this review (**Figure 19**). The included articles examined healthcare provider compliance with the following guidelines: *standard and isolation precautions* (e.g. hand hygiene, glove use, contact/droplet/airborne precautions, healthcare provider vaccination) (n=26*);* and *HAI-specific infection prevention measures* (e.g. CAUTI, CLABSI, and VAP prevention) (n=5). The study characteristics of the included articles are reported in **Table 20.** Of the studies included in this review, only n=10 (32.3%) explicitly cited behaviour change theories. A total of 368 barriers and enablers were identified and coded according to the TDF. After removing redundancies (i.e. barriers/enablers that were cited under the same theme from the same study), a total of 268 unique barriers and enablers remained. The frequency with which each barriers and enablers were identified under each TDF domain, after removing redundancies, is shown in **Table 21**. Following inductive thematic analysis, 90 total themes were identified within 13 of the 14 TDFv2 domains. **Table 22** lists all identified themes as well as the number of unique studies citing barriers, enablers, or mixed factors within each theme. No barriers or enablers were identified from the TDF domain, “optimism”.

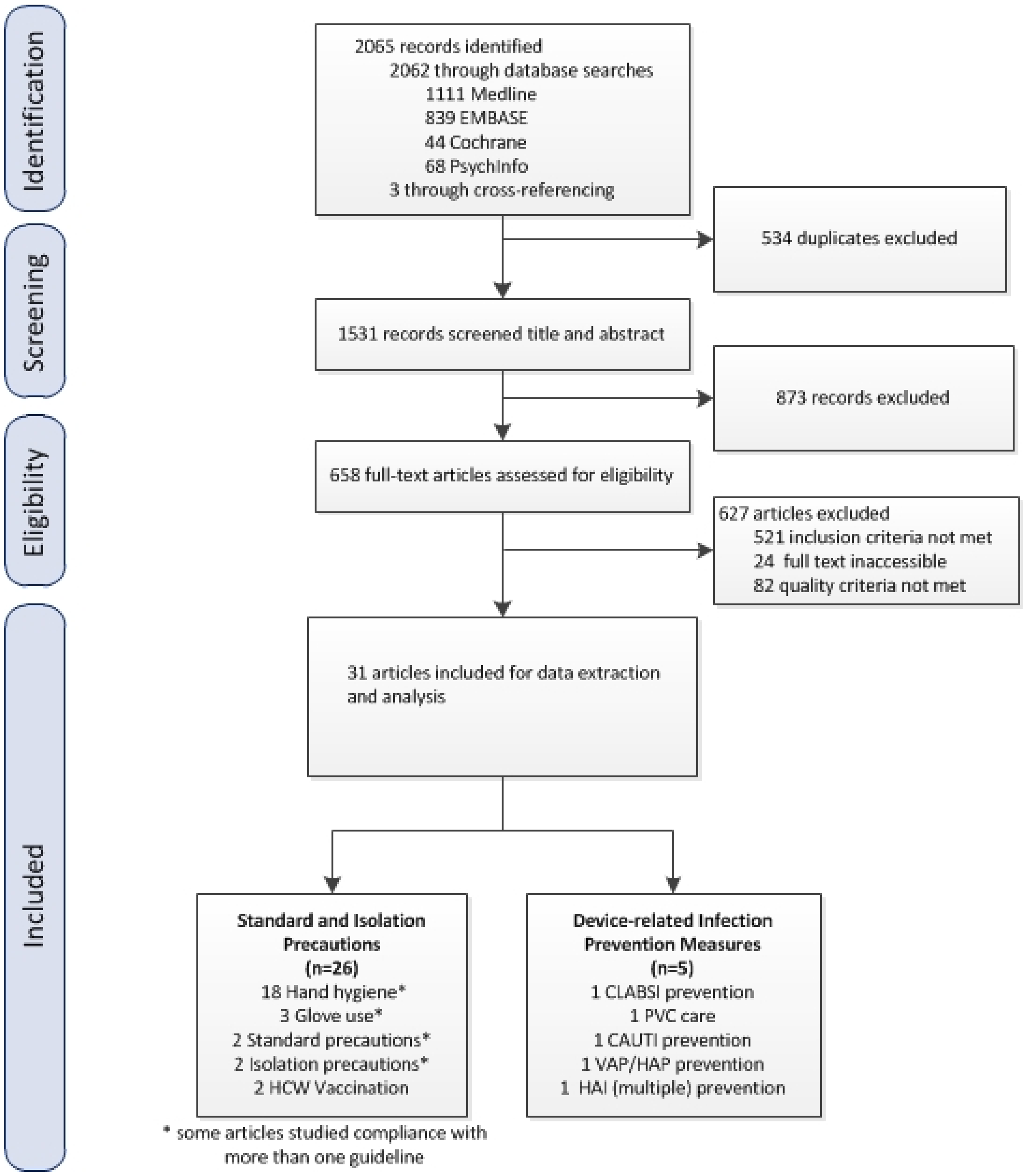

Figure 19: PRISMA flowchart of included studies

Figure 19 Legend: Flow chart of included articles based on Preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Liberati et al., 2009). Abbreviations: HCW, Healthcare worker; CLABSI, central-line-associated bloodstream infection; CAUTI, catheter-associated urinary tract infection; VAP, ventilator-associated pneumonia; PVC, peripheral venous catheter, HAP, healthcare-associated pneumonia; HAI, healthcare-associated infection.

Table 20: Details of included studies

Authors	Title	Journal	Year	IPC Guideline
Beam, Gibbs, Hewlett, Iwen, Nuss and Smith	Evaluating Isolation Behaviors by Nurses Using Mobile Computer Workstations at the Bedside	Computers, Informatics, Nursing: CIN	2016	Isolation precautions
Boog, Erasmus, de Graaf, van Beeck, Melles and van Beeck	Assessing the optimal location for alcohol-based hand rub dispensers in a patient room in an intensive care unit	BMC Infectious Diseases	2013	Hand hygiene
Borggreve and Timen	Barriers encountered during the implementation of a policy guideline on the vaccination of health care workers during the 2013-2014 measles outbreak in the Netherlands: a qualitative study	BMC Research Notes	2015	HCW Vaccination
Boudjema, Tarantini, Peretti-Watel and Brouqui	Merging video coaching and an anthropologic approach to understand health care provider behavior toward hand hygiene protocols	American Journal of Infection Control	2017	Hand hygiene / Glove use
Carter, Pallin, Mandel, Sinnette and Schuur	Emergency Department Catheter-Associated Urinary Tract Infection Prevention: Multisite Qualitative Study of Perceived Risks and Implemented Strategies	Infection Control and Hospital Epidemiology	2016	CAUTI prevention
Castro-Sánchez, Charani, Drumright, Sevdalis, Shah and Holmes	Fragmentation of care threatens patient safety in peripheral vascular catheter management in acute care--a qualitative study	Plos One	2014	PVC care
Chatfield, Nolan, Crawford and Hallam	Experiences of hand hygiene among acute care nurses: An interpretative phenomenological analysis	SAGE Open Medicine	2016	Hand hygiene
Dixit, Hagtvedt, Reay, Ballermann and Forgie	Attitudes and beliefs about hand hygiene among paediatric residents: A qualitative study	BMJ Open	2012	Hand hygiene
Erasmus, Brouwer, van Beeck, Oenema, Daha, Richardus, Vos and Brug	A qualitative exploration of reasons for poor hand hygiene among hospital workers: lack of positive role models and of convincing evidence that hand hygiene prevents cross-infection	Infection Control And Hospital Epidemiology	2009	Hand hygiene
Fitzpatrick, Pantle, McLaws and Hughes	Culture change for hand hygiene: clean hands save lives, part II	The Medical Journal Of Australia	2009	Hand hygiene
Fuller, Besser, Savage, McAteer, Stone and Michie	Application of a theoretical framework for behavior change to hospital workers' real-time explanations for noncompliance with hand hygiene guidelines	American Journal Of Infection Control	2014	Hand hygiene
Gurses, Seidl, Vaidya, Bochicchio, Harris, Hebden and Xiao	Systems ambiguity and guideline compliance: a qualitative study of how intensive care units follow evidence-based guidelines to reduce healthcare-associated infections	Quality & Safety In Health Care	2008	VAP Prevention / CLABSI prevention / SSI prevention / CAUTI prevention
Hidiroglu, Ay, Topuzoglu, Kalafat and Karavus	Resistance to vaccination: The attitudes and practices of primary healthcare workers confronting the H1N1 pandemic	Vaccine	2010	HCW Vaccination
Jackson, Lowton and Griffiths	Infection prevention as "a show": a qualitative study of nurses' infection prevention behaviours	International Journal Of Nursing Studies	2014	Standard precautions
Jang, Wu, Kirzner, Moore, Youssef, Tong, Lourenco, Stewart, McCreight, Green and McGeer	Focus group study of hand hygiene practice among healthcare workers in a teaching hospital in Toronto, Canada	Infection Control And Hospital Epidemiology	2010	Hand hygiene
Joshi, Diwan, Tamhankar, Joshi, Shah, Sharma, Pathak, Macaden and Stålsby Lundborg	Qualitative study on perceptions of hand hygiene among hospital staff in a rural teaching hospital in India	The Journal Of Hospital Infection	2012	Hand hygiene
Knoll, Lautenschlaeger and Borneff-Lipp	The impact of workload on hygiene compliance in nursing	British Journal Of Nursing (Mark Allen Publishing)	2010	Hand hygiene
LeMaster, Hoffart, Chafe, Benzer and Schuur	Implementing the central venous catheter infection prevention bundle in the emergency department: experiences among early adopters	Annals Of Emergency Medicine	2014	CLABSI prevention
Loveday, Lynam, Singleton and Wilson	Clinical glove use: healthcare workers' actions and perceptions	The Journal Of Hospital Infection	2014	Glove use
Marjadi and McLaws	Hand hygiene in rural Indonesian healthcare workers: barriers beyond sinks, hand rubs and in-service training	The Journal Of Hospital Infection	2010	Hand hygiene
McLaws, Farahangiz, Palenik and Askarian	Iranian healthcare workers' perspective on hand hygiene: A qualitative study	Journal of Infection and Public Health	2015	Hand hygiene
Nicol, Watkins, Donovan, Wynaden and Cadwallader	The power of vivid experience in hand hygiene compliance	The Journal Of Hospital Infection	2009	Hand hygiene
Picheansathian, Pearson and Suchaxaya	The effectiveness of a promotion programme on hand hygiene compliance and nosocomial infections in a neonatal intensive care unit	International Journal Of Nursing Practice	2008	Hand hygiene
Safdar, Musuuza, Xie, Hundt, Hall, Wood and Carayon	Management of ventilator-associated pneumonia in intensive care units: a mixed methods study assessing barriers and facilitators to guideline adherence	BMC Infectious Diseases	2016	VAP Prevention
Seibert, Speroni, Oh, Devoe and Jacobsen	Preventing transmission of MRSA: A qualitative study of health care workers' attitudes and suggestions	American Journal of Infection Control	2014	Contact precautions

Authors	Title	Journal	Year	IPC Guideline
Shah, Castro-Sánchez, Charani, Drumright and Holmes	Towards changing healthcare workers' behaviour: a qualitative study exploring non-compliance through appraisals of infection prevention and control practices	The Journal Of Hospital Infection	2015	Standard precautions
Squires, Linklater, Grimshaw, Graham, Sullivan, Bruce, Gartke, Karovitch, Roth, Stockton, Trickett, Worthington and Suh	Understanding practice: factors that influence physician hand hygiene compliance	Infection Control And Hospital Epidemiology	2014	Hand hygiene
Whitby, McLaws and Ross	Why healthcare workers don't wash their hands: A behavioral explanation	Infection Control and Hospital Epidemiology	2006	Hand hygiene
White, Jimmieson, Obst, Graves, Barnett, Cockshaw, Gee, Haneman, Page, Campbell, Martin and Paterson	Using a theory of planned behaviour framework to explore hand hygiene beliefs at the '5 critical moments' among Australian hospital-based nurses	BMC health services research	2015	Hand hygiene
Wilson, Bak and Loveday	Applying human factors and ergonomics to the misuse of nonsterile clinical gloves in acute care	American Journal of Infection Control	2017	Glove use
Yuan, Dembry, Higa, Fu, Wang and Bradley	Perceptions of hand hygiene practices in China	The Journal Of Hospital Infection	2009	Hand hygiene

Table 21: Number of barriers and enablers coded per domain

TDFv2 Domain	Frequency of B/E	Number of themes
11. Environmental Context and Resources	61	16
12. Social influences	48	13
1. Knowledge	31	7
10. Memory, Attention and Decision Processes	30	11
3. Social/Professional Role and Identity	29	12
6. Beliefs about Consequences	25	8
14. Behavioural Regulation	12	4
4. Beliefs about Capabilities	11	4
2. Skills	7	3
13. Emotion	6	5
9. Goals	4	3
7. Reinforcement	3	3
8. Intentions	1	1
5. Optimism	0	0
Grand Total	**268**	**90**

Table 22: List of themes and frequency of barriers, enablers, mixed factors per domain

Domain	Theme	Barriers (n)	Enablers (n)	Mixed (n)
1. Knowledge	Procedural knowledge	8	2	2
	Awareness of guidelines	2		
	Knowing which tasks had already been performed			1
	Knowledge about microbiology	3	3	
	Knowledge of contamination status	4	1	
	Knowledge of applicable guidelines	2		1
	Knowledge of evidence underlying guidelines	1	1	
2. Skills	Training		5	
	Lack of technical skill	1		
	Prior experience	1		
3. Social/Professional Role and Identity	External Policy	2		
	Lack of agreement with guidelines	1		
	Authority of IPC staff			1
	Responsibility of hospital leadership		2	1
	Division of labour	2	1	
	Ambiguity about professional responsibilities	4	2	2
	Guidelines too constraining	1		
	Lack of physician involvement	1		2
	Nurse empowerment		1	
	Generational differences in preferences	1		
	Identification of self as role model (mixed)		1	1
	Professional obligation to prevent HAI		2	1
4. Beliefs about Capabilities	Feeling incapable of challenging inappropriate practices	4		
	100% compliance with guideline is unrealistic	3		
	Guidelines are (not) easy to follow in addition to my existing workflow	1	2	
	Believing one's own practice is beyond reproach	1		
6. Beliefs about Consequences	Self-protection	3	4	2
	perceived susceptibility (of self)	1		
	Protection of family members		2	
	Protection of patients	2	1	
	Belief in efficacy of prevention measure to prevent infection	4		
	Potential for adverse effects	2		
	Patient perceptions	2		1
	Perceived severity of infection	1		
7. Reinforcement	Positive reinforcement through performance feedback		1	
	Visible rewards		1	
	Repercussions of non-compliance			1
8. Intentions	Commitment to IPC		1	
9. Goals	Communication of goals			1
	Expected standards of care	1		
	Goal priority	2		
10. Memory, Attention and Decision Processes	Decision to adopt IPC practice based on available evidence	1		
	Decision to comply with guideline influenced by non-medical criteria	1		
	Perceived dirtiness as behavioural cue			1
	Decision making based on leader opinions		1	
	Risk Assessment	3		1
	Forgetting	5		
	Reflective vs. Automatic behaviour	2	4	1
	Distraction	1		

Domain	Theme	Barriers (n)	Enablers (n)	Mixed (n)
	Biofeedback increases awareness of infectious risk		1	
	Authority for decision making	1		1
	Checklist and reminders		5	1
11. Environmental Context and Resources	Compliance is difficult in emergency situations	8		
	Lack of time	9		
	Ease of access and visibility of materials and equipment	6	4	1
	Lack of space	1		
	availability of guidelines and procedural documents	3	1	
	Characteristics of guidelines and procedural documents (i.e. consistency, clarity, emphasis, applicability)	5		
	Availability of materials and equipment	5	2	1
	Cost	1		
	Inadequate staffing	1		
	Workflow characteristics	3	2	
	cross-contamination of environment	4		
	improved technology would facilitate compliance		1	
	Individual behaviour adapted to context			1
	Isolation status			1
	Access to dermatologist to treat consequences of hand hygiene		1	
12. Social influences	(positive or negative) behaviour learnt from peers	2		1
	role modelling and leading by example improves/worsens practice	2	4	
	Perceptions of normative behaviour	4		1
	patient influence (global theme)	8	1	3
	Professional groups feeling scrutinized	1		
	Source of the intervention		1	1
	Mistrust	1		
	communication between HCWs	1	1	
	hospital/ward culture	4		1
	influence of media	1		
	Peer pressure	1	1	
	Peer support		1	2
	Intervening in peer IPC practice	2	3	
13. Emotion	Frustration due to ambiguity about responsibilities	1		
	Stress			
	Disgust			2
	Fear		2	
	Discomfort	1		
14. Behavioural Regulation	Performance feedback	2	2	1
	Compliance monitoring / Audits	2	3	
	Outcome reporting		1	
	Rationalising one's own practice	1		

The following sections narratively present the barriers and enablers identified from three domains, selected based on criteria of judged importance. These include: “social influences”, “environmental context and resources”, and “social/professional role and identity”.

Social influences

Social influences, defined as the interpersonal processes that can cause individuals to change their thoughts, feelings or behaviours (Atkins et al., 2017), emerged as a major domain in this review. Social influences were identified between HCPs and their colleagues (e.g. social norms, social pressure, role modelling) and between HCPs and patients, where HCP concerns about patient perceptions influenced their infection prevention behaviours. Regarding social influences between HCPs and their colleagues, in situations where the accepted norms were positive for infection prevention, social influences were cited as enablers for compliance with IPC guidelines. In contrast, where the social norms appeared to be counter to infection prevention, social influences such as group conformity and social pressure were seen as barriers to compliance.

> *"At times residents felt that their own learning suffered if they did not keep up with the pace of the staff physician. If their staff physician did not perform hand hygiene, the resident felt compelled to do the same to not miss any learning opportunities." (Author interpretation) (Dixit, Hagtvedt, Reay, Ballermann, & Forgie, 2012)*

Regarding social influences of patients, two sub-themes emerged. First, HCPs were concerned about maintaining the appearance of high infection prevention standards because they felt they were under scrutiny from patients.

> *''So you're doing it [wearing gloves] to prevent yourself being basically assessed by the patient as incompetent or not maintaining hygiene standards. . .. We're under thorough scrutiny by patients. They see everything you do." (Raw quote) (Jackson, Lowton, & Griffiths, 2014)*

The second primary theme involved HCPs being concerned about the negative stigma that could be perceived by patients when HCPs employ protective measures (i.e. donning gloves, hand hygiene) during patient care.

> *‘‘It is a cultural issue. Some physicians think that if they wash their hands, patients would have a bad feeling about that.’’ (Raw quote) (McLaws, Farahangiz, Palenik, & Askarian, 2015)*

> *“I mean I won’t go to every patient with gloves and apron because it makes them feel like they are dirty when they are not.” (Raw quote) (Jackson et al., 2014)*

Environmental context and resources

This domain concerns the circumstances of an individual’s organisational and physical environment that enable or inhibit that individual’s development of skills, abilities and behaviours. For this review, we considered elements of the physical environment, organisational characteristics (e.g. staffing, acuity of care), and resources (e.g. financial resources, time resources) as part of the environmental context. Also unique to this review, guidelines were considered as an organisation resource for reference, and also considered in this domain. Of the 61 factors identified in this domain, 46 (75%) were barriers to compliance with IPC guidelines. Barriers were cited in relation to missing, unclear or contradictory guidelines, lack of time necessary to perform necessary IPC behaviours, as well as critical or salient situations in which primary care tasks take precedence over IPC.

> *“[HCPs] claimed that written guidelines were sometimes inadequate and confusing, at least in some situations, and more generally too constraining and time-consuming.” (Author interpretation) (Boudjema, Tarantini, Peretti-Watel, & Brouqui, 2017)*

> *“While a nurse cares for 20 patients during a shift, she doesn’t always have the time to wash her hands for each patient.’’ (Raw quote) (McLaws et al., 2015)*

> *"There’s definitely emergency situations, I’d say that come up almost every day … sometimes you just get in there to start helping and you may not have time to get your hands sanitized or if you go in to help with whatever the situation is, if it’s an emergent need … definitely you can bypass the hand sanitizer when it’s an emergency." (Raw quote) (Chatfield, Nolan, Crawford, & Hallam, 2016)*

A mixed theme, availability and design of hand hygiene resources were cited as facilitators to hand hygiene compliance when these were available, or as barriers to hand hygiene when missing.

> *“All nursing personnel shared one opinion in common that the availability of alcohol dispensers facilitated nursing personnel to clean their hands more frequently.” (Author interpretation) (Picheansathian, Pearson, & Suchaxaya, 2008)*

> *‘‘Sometimes we want to wash our hands, but liquid soap does not exist at all.’’ (Raw quote) (McLaws et al., 2015)*

Social/professional role and identity

Social and professional role and identity concerns the set of behaviours and personal characteristics displayed or believed to be important for individuals in a social or professional setting (Atkins et al., 2017). Within this domain, ambiguity about professional responsibilities was cited as a major barrier to IPC compliance. This theme emerged primarily in relation to compliance with more complex HAI-specific prevention behaviours, where different professional group were unclear about their responsibilities.

> *"During morning rounds, the resident may report the glucose range from 140 to 160 and no one in the team says anything. It is nurses’ responsibility to keep it that tight*

but if it is not that tight no one follows up with it. No one asks why is it above 120? Why can't we get it under control? Then, the nurses will think ''Well, they did not mention anything so what I am doing is probably fine.'' (Raw quote) (Gurses et al., 2008a)

"'It's [managing peripheral vascular catheters] quite a grey area, the doctor will say it's the nurse and the nurse will say well the doctor [who] put it in. They're quite antagonistic with each other." (Raw Quote) (Shah, Castro-Sánchez, Charani, Drumright, & Holmes, 2015)

Conversely, identification of one's self as a role model and perceiving a professional obligation to prevent HAI were enablers, particularly for hand hygiene compliance.

"All physicians felt they were leaders of HH and should serve as role models to other staff members" (Author interpretation) (McLaws et al., 2015)

"First of all, I feel responsible for the person that I am dealing with. That's where it really impacts me. If I touch somebody and I haven't washed my hands properly, then I am going to be the carrier and trigger for that MRSA to go forward. And to think what happens to people!" (Raw quote) (Seibert, Speroni, Oh, Devoe, & Jacobsen, 2014)

DISCUSSION

The detailed analysis of the results presented in this chapter is currently ongoing. The following section discusses these preliminary results, and outlines the steps planned for further analysis.

This review revealed a wide range of behavioural determinants that have been qualitatively studied in relation to healthcare provider compliance with various infection prevention guidelines. The majority of identified studies (n=26, 84 %) examined determinants of HCP compliance with guidelines on standard and isolation precautions – most of which looked predominantly at compliance with hand hygiene (n=18, 69%). Studies examining HCP compliance with guidelines for specific HAI prevention made up only 16% (n=5) of included studies.

In this review of qualitative literature, a higher percentage of studies were found to include mention of theory (32.3%), than previous reviews including quantitative studies (0-14%) (Edwards et al., 2012; Clack et al., (unpublished BAG report)).

Due to the limited number of studies addressing compliance with certain guidelines, the results of this review are primarily presented as barriers and enablers across all types of guidelines. It is worth noting, however, that some barriers and enablers were unique to different types of guidelines. This is unsurprising given that different guidelines entail behaviours of varying complexity, requiring different levels of skill. For example, lack of technical skill did not emerge as a barrier to performing hand hygiene, but it did emerge for catheter-insertion technique relative to CLABSI prevention. A next step will be to assess how exactly identified barriers and enablers varied for different types of behaviours.

The TDF proved to be a useful framework to guide this secondary data analysis. The explicit use of theoretical constructs allowed conceptualising a wide range of potential determinants of infection prevention behaviours. The combination of deductive coding based on TDF domains followed by inductive thematic analysis was a strength of this study. This two-part analysis entailed first identifying and coding relevant barriers and enablers according to established theoretical constructs and then inductively allowing unanticipated findings to emerge.

Another specific advantage of using the TDF to guide this review is that the TDF domains have been mapped onto a list of intervention functions that are likely to be effective in bringing about behaviour change (Michie et al., 2008; Cane, Richardson, Johnston, Ladha, &

Michie, 2015). These mappings are the result of expert consensus and they link identified barriers and enablers within TDF domains to “active intervention ingredients”. The intervention functions that are likely to be effective in addressing the TDF domains that were of greatest importance in this study are listed in **Table 23**.

The implications of this review’s findings for intervention design will be further discussed in the general discussion section 7.

Table 23: Theoretical domains mapped onto suggested intervention functions

TDF Domain	Suggested Intervention Functions
Environmental context and resources	Training Restriction Environmental restructuring Enablement
Social influences	Restriction Environmental restructuring Modelling Enablement
Social/professional role and identify	Education Persuasion Modelling

ANNEX 1. SEARCH STRATEGIES

Cochrane: ((infection near/3 (control or management or prevention)):ti,ab,kw or (antimicrobial near/3 (stewardship or prescription or prescribing)):ti,ab,kw or ('Methicillin Resistant Staphylococcus Aureus' or 'clostridium difficile' or C-diff or 'nosocomial infection') and (control or prevention or management or guideline* or precaution*):ti,ab,kw (Word variations have been searched)) AND (((clinical or nursing or standard or hygiene or handwashing) near/3 (protocol or instruction* or procedure* or polic* or practice or recommendation*)):ti,ab,kw or (universal near/1 precautions):ti,ab,kw or guideline*:ti,ab,kw (Word variations have been searched)) AND ((('health care' or hospital or medical or nursing or healthcare) near/3 (personnel or staff or worker* or student*)):ti,ab,kw or physician* or doctor* or surgeon* or nurse* or practitioner*:ti,ab,kw (Word variations have been searched)) AND (hospital* or clinic:ti,ab,kw (Word variations have been searched)) AND ((determinants or motivation or compliance or noncompliance or adherence or behavi* or attitude*):ti or ((determin* or motivat* or influenc* or behav* or psychosocial) near/3 (factor* or variables)):ti,ab,kw or ((determin* or measure* or assess* or estimat* or influenc* or effect* or improv* or observ* or chang*) near/6 (compliance or noncompliance or adherence or behavi* or attitude*)):ti,ab,kw (Word variations have been searched))

Embase: (('health personnel attitude'/exp OR 'behavior change'/exp OR 'behavior'/de OR 'behavior theory'/exp OR 'adaptive behavior'/exp OR 'attitude to health'/exp OR 'health behavior'/de OR 'motivation'/exp OR 'medical decision making'/exp) AND (determinants:ab,ti OR motivation:ab,ti OR behavior:ab,ti OR behaviour:ab,ti OR attitude*:ab,ti OR (((determin* OR motivat* OR influenc* OR behav* OR psychosocial) NEAR/3 (factor* OR variables)):ab,ti)) OR (((determin* OR measure* OR assess* OR estimat* OR influenc* OR effect* OR improv* OR observ* OR chang*) NEAR/6 (compliance OR noncompliance OR adherence OR behavi* OR attitude*)):ab,ti) OR compliance:ti OR noncompliance:ti OR adherence:ti OR behavi*:ti OR attitude*:ti) AND ('medical practice'/exp OR 'professional practice'/de OR 'hospital'/exp OR hospital*:ab,ti OR clinic:ab,ti) AND ('health care personnel'/exp OR ((('health care' OR hospital OR medical OR nursing OR healthcare) NEAR/3 (personnel OR staff OR worker* OR student*)):ab,ti) OR physician*:ab,ti OR doctor*:ab,ti OR surgeon*:ab,ti OR nurse*:ab,ti OR practitioner*:ab,ti) AND ('practice guideline'/exp OR 'clinical practice'/exp OR (((clinical OR nursing OR standard OR hygiene OR handwashing) NEAR/3 (protocol OR instruction* OR procedure* OR polic* OR practice OR recommendation*)):ab,ti) OR ((universal NEAR/1 precautions):ab,ti) OR guideline*:ab,ti) AND ('hand washing'/exp OR 'hygiene'/exp OR 'infection control'/exp OR 'infection prevention'/exp OR ((infection NEAR/3 (control OR management OR prevention)):ab,ti) OR ((antimicrobial NEAR/3 (stewardship OR prescription OR prescribing)):ab,ti) OR (('methicillin resistant staphylococcus aureus'/exp OR 'peptoclostridium difficile'/exp OR 'hospital infection'/exp OR 'disease transmission'/exp OR 'virus transmission'/exp OR 'methicillin resistant staphylococcus aureus':ab,ti OR 'clostridium difficile':ab,ti OR 'c diff':ab,ti OR 'nosocomial infection':ab,ti) AND (control:ab,ti OR prevention:ab,ti OR management:ab,ti OR guideline*:ab,ti OR precaution*:ab,ti)) AND ([english]/lim OR [french]/lim OR [german]/lim)

PsychInfo via EBSCOhost: (((DE "Health Personnel Attitudes" OR DE "Therapist Attitudes" OR DE "Attitude Change" OR DE "Behavior Change" OR DE "Behavior Therapy" OR DE "Behavior" OR DE "Motivation" AND DE "Decision Making" OR DE

"Decision Support Systems" OR DE "Positive Psychology" OR DE "Organizational Behavior" OR DE "Organizational Commitment" OR DE "Organizational Learning"))) OR (TI ((determinants OR motivation OR behavior OR behaviour OR attitude*) OR AB ((determinants OR motivation OR behavior OR behaviour OR attitude*) OR TI ((determin* OR motivat* OR influenc* OR behav* OR psychosocial) N3 (factor* OR variables)) OR AB ((determin* OR motivat* OR influenc* OR behav* OR psychosocial) N3 (factor* OR variables)))) OR (TI ((determin* OR measure* OR assess* OR estimat* OR influenc* OR effect* OR improv* OR observ* OR chang*) N6 (compliance OR noncompliance OR adherence OR behavi* OR attitude*)) OR AB ((determin* OR measure* OR assess* OR estimat* OR influenc* OR effect* OR improv* OR observ* OR chang*) N6 (compliance OR noncompliance OR adherence OR behavi* OR attitude*))) OR TI (compliance OR noncompliance OR adherence OR behavi* OR attitude*)) AND (DE "Clinics" OR DE "Child Guidance Clinics" OR DE "Psychiatric Clinics" OR DE "Walk In Clinics" OR DE "Hospitals" OR DE "Psychiatric Hospitals" OR DE "Sanatoriums" OR DE "Intensive Care" OR DE "Neonatal Intensive Care"OR TX (hospital* OR clinic) OR TX(("critical care" OR emergency) N3 unit*)) AND (DE "Medical Personnel" OR DE "Nurses" OR DE "Physicians" OR DE "Health Personnel" OR TX (('health care' OR hospital OR medical OR nursing OR healthcare OR surgical) N3 (personnel OR staff OR worker* OR student* OR ward*)) OR TX (physician* OR doctor* OR surgeon* OR nurse* OR practitioner*)) AND ((DE "Professional Standards") OR (DE "Best Practices") OR TX ((clinical OR nursing OR standard OR hygiene OR handwashing) N3 (protocol OR instruction* OR procedure* OR polic* OR practice OR recommendation*)) OR TX ((universal OR standard) N1 precautions) OR TX guideline*) AND (((DE "Hygiene") OR TX (infection N3 (control OR management OR prevention)) OR TX (antimicrobial N3 (stewardship OR prescription OR prescribing))) OR (((DE "Disease Transmission") OR TX ('Methicillin Resistant Staphylococcus Aureus' OR 'clostridium difficile' OR C-diff OR 'nosocomial infection')) AND (TI (control OR prevention OR management OR guideline* OR precaution*) OR AB (control OR prevention OR management OR guideline* OR precaution*)))

Medline via EBSCOhost: (((((MH "Guideline Adherence") OR (MH "Attitude of Health Personnel+") OR (MH "Health Knowledge, Attitudes, Practice") OR (MH "Behavior") OR (MH "Behavior Therapy") OR (MH "Cooperative Behavior") OR (MH "Behavior Rating Scale") OR (MH "Behavior Observation Techniques") OR (MH "Behavior and Behavior Mechanisms") OR (MH "Attitude+") OR (MH "Motivation+") OR (MH "Clinical Decision-Making"))) AND (TI ((determinants OR motivation OR behavior OR behaviour OR attitude*) OR AB ((determinants OR motivation OR behavior OR behaviour OR attitude*) OR TI ((determin* OR motivat* OR influenc* OR behav* OR psychosocial) N3 (factor* OR variables)) OR AB ((determin* OR motivat* OR influenc* OR behav* OR psychosocial) N3 (factor* OR variables)))) OR (TI ((determin* OR measure* OR assess* OR estimat* OR influenc* OR effect* OR improv* OR observ* OR chang*) N6 (compliance OR noncompliance OR adherence OR behavi* OR attitude*)) OR AB ((determin* OR measure* OR assess* OR estimat* OR influenc* OR effect* OR improv* OR observ* OR chang*) N6 (compliance OR noncompliance OR adherence OR behavi* OR attitude*))) OR TI (compliance OR noncompliance OR adherence OR behavi* OR attitude*))) AND ((MH "Practice Management, Medical+") OR (MH "Hospitals+") OR (MH "Ambulatory Care Facilities") OR (MH "Academic Medical Centers+") OR (MH "Hospital Units+") OR TX (hospital* OR clinic) OR TX(("critical care" OR emergency) N3 unit*)) AND ((MH "Health Personnel+") OR TX (('health care' OR hospital OR medical OR nursing OR healthcare OR surgical) N3 (personnel OR staff OR worker* OR student* OR ward*)) OR TX (physician* OR doctor* OR surgeon* OR nurse* OR practitioner*)) AND ((MH "Guidelines as Topic") OR (MH "Practice Guidelines as Topic") OR (MH "Guideline+") OR TX ((clinical OR nursing OR standard Or hygiene OR handwashing) N3 (protocol OR instruction* OR procedure* OR polic* OR practice OR recommendation*)) OR TX ((universal OR standard) N1 precautions) OR TX guideline*) AND (((MH "Hand Hygiene+") OR (MH "Hygiene")OR (MH "Infection Control+") OR (MH "Cross Infection+/PC") OR (MH "Disease Transmission, Infectious/PC") OR TX (infection N3 (control OR management OR prevention)) OR TX (antimicrobial N3 (stewardship OR prescription OR prescribing))) OR (((MH "Methicillin- Resistant Staphylococcus aureus") OR (MH "Clostridium difficile") OR (MH "Cross Infection+") OR (MH "Disease Transmission, Infectious+") OR TX ('Methicillin Resistant Staphylococcus Aureus' OR 'clostridium difficile' OR C-diff OR 'nosocomial infection')) AND (TI (control OR prevention OR management OR guideline* OR precaution*) OR AB (control OR prevention OR management OR guideline* OR precaution*)))

7. CHAPTER 7: OVERALL DISCUSSION

The following section includes an overarching discussion of the major results from the eight studies included in this thesis. Strengths (7.3) and limitations (7.4) of these studies and the overall approach are discussed, followed by research and practical implications (7.5) and general conclusions (7.6).

7.1. DISCUSSION OF MAJOR RESULTS

Altogether, the work presented in this thesis aimed to develop and demonstrate the applicability of a behavioural science paradigm to guide infection prevention efforts. The following summary and discussion of major results is presented in two parts corresponding to the two primary study questions emerging from this paradigm.

7.1.1. Part 1: Identify and define the behaviours relevant to infectious risks.

This thesis presented two primary methods for addressing identifying and establishing the frequency of HCP behaviours potentially relevant to infectious risks (Part 1). These methods included 1) exploratory and structured direct observations and 2) indirect observations using video recording. Given that a broad range of potential infectious risk behaviours were identified, an additional method, expert consensus using a modified Delphi process, was employed for assessing the clinical relevance and prioritising identified infectious risk behaviours.

Infectious risk identification method 1 – direct exploratory and structured observations. First, exploratory direct observations were undertaken to identify behaviours potentially resulting in the transmission of microorganisms to patients. These behaviours were termed “infectious risk moments” (IRM), as reported initially in a pilot study (30 hours), then confirmed during an extended study including 130 hours of exploratory observations. Based on these exploratory observations, the INFORM structured taxonomy was established to classify IRM according to the source, vector, and endpoint of microorganisms involved in the IRM transmission pathway. The INFORM structured taxonomy was then employed during structured direct observations to quantify the frequency and type of IRM in three distinct care settings: an intensive care unit, general medical ward, and emergency ward (including trauma). IRM involving HCP hands, gloves, medical devices, mobile objects, invasive devices, and HCP clothing and accessories were found to occur, on average, 42.8 times per hour of active care. In other words, HCP behaviours that potentially transmit microorganisms to patients were found to occur, on average, once every 1.4 minutes.

Infectious risk identification method 2 – indirect observations using video. In a parallel stream of research, complementary to the IRM approach, indirect observations were conducted using a GoPro head-mounted camera to capture all hand-to-surface exposures (HSE) of HCPs during patient care that may result in transmission of microorganism throughout the healthcare environment and to patients. Videos from 296.5 minutes of care were systematically analysed using a video coding software ex-situ, revealing that HSE occurred, on average, once every 4.2 seconds. Sequential analysis further revealed that 291 of the observed HSEs involved transitions from outside to inside the patient zone, i.e. “colonisation events”, or behaviours potentially resulting in colonisation of the patient and his/her surroundings with microorganisms foreign and potentially harmful to the patient. While these HSE only involved HCP hands (and not other mobile objects, devices, and apparel, as in the IRM approach), these colonisation events were found using this systematic approach to occur once per 1.01 minutes

Establishing clinical relevance of IRM. Upon establishing the high frequency with which IRM occur during acute patient care, an expert consensus study using a modified Delphi approach was undertaken to establish expert opinion on the clinical relevance of IRM. Based on a representative selection of 52 archetypical IRM, mean ratings across all IRM scenarios for likelihood of colonisation and infection were 2.68 (low-medium) and 2.02 (low), respectively.[i] The consensus expert assessments for each IRM scenario presented were plotted against frequency data from the previous structured observation study, resulting in a quantitative IRM risk index. This IRM risk index revealed that the IRM with the highest risk

[i] Experts rated likelihood using the following scale: 0, none; 1, very low; 2, low; 3, medium; 4, high; or 5, very high.

indices, and thus conceptually the highest clinical relevance, are those that combine medium likelihood of infectious outcome with high frequency, occurring more than twice per hour of patient care. Examples of such behaviours included:

(a) programming an infusion pump wearing gloves (*vector: gloves*) that had been worn for an extended period of time, touching multiple surfaces in the room (*sources: environment, medical device*), then manually verifying a peripheral catheter insertion site (*endpoint: patient critical site*);

(b) after touching multiple surfaces in the healthcare environment (*source: environment, outside patient room*), entering a patient's room then, without hand hygiene (*vector: HCP hands*), preparing and administering intravenous medication (*endpoint: critical site*); and

(c) after having touched several surfaces in the healthcare environment, entering a patient room then (*source: environment, outside patient room*), without hand hygiene, pulling gloves out of the box and donning the gloves (*vector: gloves, donning without hand hygiene)* then touching the patient's open wound (*endpoint: critical site*).

Interestingly, IRMs with the highest risk indices also had in common that they often involved potential transfer of microorganisms directly to patient critical sites, and often involved unsafe use of gloves.

Discussion of Part 1 results: It is worth noting that the video coding approach to identify HSEs found a higher frequency of colonising HSE events (1 colonising HSE event per 1.01 minutes) involving hands alone, than the frequency of IRM involving all possible vectors found using direct live observations by two observers. This finding suggests that despite efforts to identify all potential IRM during live observation by two observers, it is likely that some potentially relevant behaviours may have been missed due to limited observer capacity.

This would imply that the IRM frequency reported here may actually be a slight underestimation.

Together these studies demonstrate that while HCP hands indeed play an important role in the transmission of microorganisms through their frequent contacts with objects and surfaces throughout the healthcare environment, other behaviours beyond hand hygiene are also involved in microorganism transmission and may be of clinical relevance. These behaviours include the unsafe use of gloves, care devices, mobile objects, and HCP clothing and accessories.

Whereas traditional infection prevention studies employ a rule-based approach to assessing clinical risks (e.g. evaluating hand hygiene compliance based on established patient-zone based indications), the studies presented in this thesis suggest that such rule-based approaches may have overlooked a portion of infectious risk behaviours that have not yet been addressed by rules and guidelines. This is true even for the well-established field of hand hygiene, where, although the patient zone concept is conceptually useful to guide hand hygiene efforts, this thesis found that colonisation events likely to introduce foreign microorganisms to the patient zone occurred approximately once every minute. This introduces the possibility that the patient's direct surroundings are no longer contaminated uniquely with the patient's own flora. Whereas current hand hygiene guidelines do not require hand hygiene between contacts with the patient's direct environment (i.e. surfaces inside patient zone) and the patient based on the assumption that both are contaminated by the same flora (*WHO guidelines on hand hygiene in health care.* , 2009), the current results are grounds for questioning this assumption.

Summary of findings for Part 1: Together, the structured observations and expert consensus studies resulted in the establishment of a comprehensive inventory of IRM behaviours with associated expert assessments of relative clinical relevance. The comprehensive IRM inventory identifies the full range of HCP behaviours that may be involved in transmission of microorganisms that could cause patient harm throughout the healthcare environment. The IRM risk index assigns clinical relevance to each type of IRM based on expert ratings of likelihood of infectious patient outcomes and IRM observed frequencies. Together, the comprehensive IRM inventory and corresponding risk index lay the ground for prioritising which HCP behaviours should be addressed to prevent transmission of microorganisms.

7.1.2. Part 2: Identify the factors that influence HCP infectious risk behaviours.

In line with the behavioural science paradigm for infection prevention, Part 2 involved a mixed-methods behavioural analysis to identify the factors that influence relevant HCP infectious risk behaviours. This thesis employed both empirical and theoretically informed data synthesis methods to understand these factors. Empirical methods were necessary because the specific behaviours identified by the IRM approach have not been the subject of previous studies. Two empirical methods relatively novel to the field of infection prevention, namely concept-mapping and video-reflexive ethnography, were employed to inductively identify behavioural determinants of IRM behaviours. A systematic review of literature guided by the Theoretical Domains Framework was also conducted to identify the full range of behavioural determinants that have already been explored in published literature in relation to compliance with existing infection prevention guidelines.

Empirical behavioural analysis method 1 – concept-mapping: The first study presented in Chapter 5 sought to iteratively develop and test the feasibility of a concept-mapping method that would uncover the underlying beliefs and cognitive processes that make up HCP mental models. Over four rounds of iterative development, a method was established that involved a card-sorting activity (Budhwar, 2000) combined with a think-aloud protocol (Davey, 1983). The benefit of this dual-method approach is that it allowed for triangulation of mental models based on how participants sorted the provided cards and the thoughts they verbalised throughout the think-aloud protocol. The concept-mapping method was then employed with a sample of 12 HCPs to understand HCP mental models about the patient zone. The patient zone was as a topic of interest given the observations from part 1 that identified infectious risk behaviours, both IRM and HSE, frequently involved potential transmission of microorganisms between surfaces in the patient's direct surroundings and the greater healthcare environment. This study revealed that the patient zone concept, as defined in hand hygiene literature and guidelines, is not a well-known concept to all frontline HCPs. The study further found that significant disagreement exists, particularly between professional groups, about which items and surfaces should belong to the patient zone.

Empirical behavioural analysis method 2: The second behavioural analysis method employed in this thesis was video-reflexive ethnography based on reflexive, semi-structured interviews with 40 HCPs. This study was specifically designed to explore the physical, social, and cognitive processes that influence HCP behaviours relevant to infection prevention in general and specific to identified IRM. Following deductive analysis using the TDF and inductive thematic analysis to identity emerging themes, the following domains emerged as being highly relevant to HCP infection prevention behaviours: "Environmental Context and Resources" (n=416, 7 themes) [e.g. lack of time, staffing]; "Knowledge" (n=276, 5 themes) [e.g. knowledge of guidelines, knowledge of hygiene status] ; "Nature of the Behaviour" (n=244, 5 themes) [e.g. conscious vs. unconscious behaviours, routine vs. non-routine tasks]; "Beliefs about Consequences" (n=243, 6 themes) [e.g. likelihood of patient infection, self-protection]; "Memory, Attention, and Decision Processes" (n=154, 6 themes) [e.g. forgetting, distraction]; and "Social Influences" [e.g. positive and negative role-models, patient perception], (n=99, 6 themes).

Systematic literature review. To complement the empirical studies in this thesis with findings from published literature, a systematic literature review was done. The review included 31 qualitative studies that used exploratory methods to understand barriers and enablers to HCP compliance with established infection prevention guidelines. The TDF was also used as an overarching theoretical framework in this study to guide categorisation of the extracted barriers and enablers into theoretical construct domains. A similar analytical approach was used as the for the video-reflexive study, involving first a deductive coding of identified barriers and enablers according to TDF domains, followed by inductive thematic analysis to identify emerging insights. The domains that emerged as being highly relevant to HCP compliance with infection prevention guidelines included "social influences" (n=48, 13 themes) [e.g. patient influence, role modelling], "environmental context and resources" (n=61, 16 themes) [e.g. lack of time, ease of access to materials], and "social/professional role and identity" (n=29, 12 themes) [e.g. ambiguity about professional responsibilities].

Discussion of part 2 results. The application of multiple methods within this thesis allows for triangulation of barriers and identified empirically based on qualitative research methods and theoretically based on analysis of published literature. Because the TDF was the guiding framework for both the video-reflexive ethnography study and the systematic literature review, it is possible to compare the results of these studies based on the domains that emerged as being of high relevance. Table 24 displays the six domains that were found to be of highest relative importance in each study.

Table 24: Domains of highest relative importance across studies

Video-reflexive ethnography			Systematic Literature Review		
Domain	Frequency	Themes	Domain	Frequency	Themes
11. Environmental Context and Resources	416	7	11. Environmental Context and Resources	61	16
1. Knowledge	276	5	12. Social influences	48	13
15. Nature of the behaviours	244	5	1. Knowledge	31	7
6. Beliefs about Consequences	243	6	10. Memory, Attention and Decision Processes	30	11
10. Memory, Attention and decision Processes	154	6	3. Social/Professional Role and Identity	29	12
12. Social influences	99	6	6. Beliefs about Consequences	25	8

Table 24 Legend: domains that did not emerge as highly important in both studies are listed in grey.

Interestingly, five of the six domains that were found to be of highest importance were the same in both studies and the domain, “environmental context and resources” was the most frequently coded and most elaborated[ii] domain in both studies. In both studies, the themes that emerged under the environmental context domain were primarily barriers related to inadequate resources (e.g. time, personnel, and materials) necessary to perform adequate infection prevention measures, as well as competing circumstances (e.g. urgent or salient events) that prevented infection prevention behaviours from being performed. Themes related to knowledge that emerged from both studies were also most often cited as barriers related to missing knowledge of guidelines for infection prevention, as well as missing or inaccurate knowledge of microbiology and transmission dynamics. Another highly relevant theme that emerged within the knowledge domain in both studies was “knowledge about contamination status”, where missing knowledge about what items and surfaces in the physical environment were contaminated was a barrier to safe infection prevention behaviour. This theme is closely related to findings of our concept-mapping study, which found that, among a sample of 10 frontline HCPs, many lacked knowledge and had low levels of agreement about which items in the environment belong to the patient zone. Although the TDF was not used as a guiding framework for the concept-mapping study, many of the results emerging from the study would likely fall under the domains of knowledge and environmental context and resources as well. The implications of these findings for the design of infection prevention initiatives is discussed in a later section (7.5).

[ii] Elaboration defined as a function of the number of themes inductively identified within the domain.

7.2. DISCUSSION OF METHODOLOGICAL ASPECTS

The methodological strengths and limitations of the eight studies will be discussed in the following section, with particular focus on the design and sample. The strengths and limitations of the overall approach will be discussed in later sections (7.3 and 7.4)

7.2.1. Design

Studies 1 and 2 employed direct exploratory and structured observations to identify behaviours potentially involved in microorganism transmission (IRM), while Study 3 used a head-mounted video camera for indirect observations of hand-to-surface contacts potentially relevant for microorganism transmission (HSE). For both direct and indirect observation methods, it is possible that a Hawthorne effect may have influenced the behaviour of HCPs being observed (Parsons, 1974). Efforts were made to minimize Hawthorne effect during live observations because the observers were discreet and did not interfere with the tasks being conducted. While filming, anecdotal reports from participating HCPs who said that they often forgot that they were wearing the head camera and being filmed, suggest that the Hawthorne effect likely diminished throughout each observation session. In all observation studies, participants were told that the aim of the study was to investigate potential infectious risks, but not exactly which behaviours were being observed. It is therefore unlikely that being observed resulted in systematic bias in HCP behaviour.

Two observers were present at all times during the structured observations reported in Study 2. To ensure high quality of observations, we used two quality measures. First, percent agreement between the two observers was calculated to measure sensitivity (detection of the same IRM). Second, for moments that were independently identified by both observers, Cohen’s kappa was calculated to determine inter-observer agreement (consistent classification of IRM). Having two observers present at all times is both costly and exceptional for observation studies, which usually only include two observers during an initial validation period and then continue with single observers. Nonetheless, the decision to keep two observers throughout the entire observation period was made to ensure that the as many of the occurring IRM as possible were captured by at least one observer (i.e. highest possible sensitivity). Despite these efforts, it is possible that some IRM were missed, and that the resulting frequencies may be slight underestimations. The indirect observations reported in Study 3, in contrast, were able to systematically record all HSE within range of the recording head-camera. Although the process of manually coding video data is time consuming, this method may offer a more accurate estimation of frequency than is possible with live observers.

The Delphi processes reported in Study 5 was used to establish expert consensus on the clinical relevance of identified IRM. Expert consensus was sought to assess clinical relevance of IRM given the limited microbiological data that currently supports the proof of microorganism transmission linked to specific behaviours or to the likelihood of infectious patient outcomes. Expert opinion, may however, be subject to bias and remains an imperfect surrogate to actual microbiological studies demonstrating the clinical relevance of transmission-related behaviours. Another limitation of the Delphi process design is that experts rated the likelihood of infectious outcomes on a Likert scale from 0 – 5, resulting in rankings of the relative importance of IRM. What these ratings do not provide, however, is an indication about the magnitude or scale of the risk of individual IRM. It is therefore imperative that more extensive microbiological studies be conducted, and that IRM be continually assessed for clinical relevance as this evidence becomes available.

Studies 5, 6, and 7 develop and apply qualitative methods to understand the factors that influence HCP behaviours relative to infectious risks. These methods were intended to reveal relevant physical, social, and cognitive processes through innovative elicitation techniques. The concept-mapping studies 5 and 6 both employed a card-sorting technique whereby participants sorted items on physical or virtual cards into categories while “thinking-aloud” their thoughts throughout the process. In itself, the concept-mapping methodology as developed and applied in this thesis represents a mixed-method approach because it offers both quantitative data from the sorting, as well as qualitative data explaining the thoughts and ideas behind the sorting.

Study 7 used review of filmed care sequences as an elicitation technique during reflexive semi-structured interview sessions. A specific advantage of video-reflexive ethnography is that it allows HCPs to view and reflect on their own work practices in general and specifically as they relate to infection prevention (Iedema et al., 2015). Although this study was designed using the TDF and CFIR as sensitising frameworks to identify a wide range factors potentially influencing HCP behaviours, it is possible that some relevant factors may have been overlooked. The role of the researcher is also important for qualitative studies, where the characteristics of the individual(s) conducting the research may influence data collection and analysis (Tong, Sainsbury, & Craig, 2007). Participants were informed that these studies were being conducted by researchers from the infection prevention department, which may have influenced the information they provided. Efforts were made to avoid desirability bias by informing all participants that the aim was to learn from their experience about what enables or hinders infection prevention practices and that there were no correct or incorrect answers. Also to avoid personal biases due to researcher characteristics, individuals with varying expertise (e.g. psychology, nursing, medicine) were involved at different times throughout the data collection and analysis. Another important strength of the video-reflexive technique is that it actively involves HCPs in critical reflection about their practice, which may actually act as an intervention in itself. This catalytic validity was assessed using a post-participation survey 2 weeks following participation in the reflexive interview. While this survey measured the self-reported changes in awareness and behaviour with respect to infection prevention, it is an imperfect measure of the impact of the video-reflexive exercise.

The final study in this thesis, Study 8, was a systematic literature review to identify facilitators and barriers to compliance with established infection prevention guidelines and the TDF served as a guiding framework. Despite stringent efforts to identify relevant literature from both psychology and medical databases, relevant studies may have been overlooked. Further, despite efforts to identify and extract all reported barriers and facilitators from included studies, and to verify data extraction by multiple reviews, some relevant factors reported in included studies may have been overlooked. The systematic literature further includes only studies that employed qualitative research methods (e.g. interviews). A larger review that also includes studies using quantitative methods (e.g. observational studies, questionnaire studies) to explore barriers and facilitators is currently underway.

7.2.2. Sample

Six of the eight studies presented in this thesis were conducted in a single university-affiliated, 900-bed tertiary care hospital located in Zurich, Switzerland, a high-income setting. Although these studies are limited to one hospital, active efforts were made to include a variety of care settings (e.g. intensive care, general medical, emergency and trauma wards) in which a wide range of activities and potential infectious risks could be observed. Individual participants for specific studies were also purposefully sampled to include a mix of professions (i.e. both nurses and physicians) from different care settings.

For the Delphi expert consensus, Study 4, a group of experts from different professions (physicians, nurses, and microbiologists) with different specialisations (infectious diseases, infection prevention) was purposefully sampled. Furthermore, these experts represented multiple geographic regions to include Europe (67.5%, n=27), The Americas (20%, n=8), and The Western Pacific (12.5%, n=5). Although the behaviours assess in this study were observed in only one hospital, the expert assessment of their clinical relevance is based on a global sample of experts.

7.3. Strengths

A major strength of this thesis lies in the exploratory approach, grounded in the established behavioural sciences paradigm, to first identify and prioritise relevant infectious risk behaviours, and then explore in depth the factors that influence these behaviours. The work presented here thus goes beyond assessing compliance with existing guidelines, and instead presents a systems approach to identify and prioritise infectious risks.

A further strength lies in the use of multiple methods during each part of the project. During part 1, identifying and prioritising infectious risk behaviours, the use of multiple methods allowed for comparing the frequency of IRM based on direct observations with the frequency of HSE based on indirect observations. During part 2, identifying the factors the influence infectious risk behaviours, both empirical and theoretically informed evidence synthesis methods were employed, which allowed for triangulation between methods and strengthened the overall approach. Furthermore, two of these studies used the same guiding framework, the TDF, which further facilitated the comparison of study outcomes. The use of the TDF as a guiding framework is also a strength of this study, particularly given that the framework has been validated by international behaviour change experts and mapped onto The Behaviour Change Wheel (BCW) (Cane et al., 2012; Michie et al., 2014a). The BCW is a synthesis of existing behaviour change frameworks that links the sources of behaviour to different types of interventions, termed intervention functions, which specifically address the identified barriers and enablers to performing a specific behaviour. A key benefit of the BCW, particularly as it relates to the systematic approach employed in this thesis, is that it encourages consideration of the full range of behaviour-change options and selection based on those that are likely to be the most promising based on existing theory and evidence (Michie et al., 2014a).

A final strength of this approach is the stepwise, cumulative approach. As demonstrated in Figure 6, the outcomes of each study informed and shaped the design of subsequent studies. The exploratory observations resulted in a structured taxonomy that made the classification and quantification of IRM possible. The Delphi expert consensus study was based on a representative selection of observed IRM. The concept-mapping studies were then developed to specifically address topics that emerged from the observation studies as highly relevant. The video-reflexive ethnography study then continued with the IRM approach, drawing participants' attention to and seeking to understand the factors that influenced behaviours surrounding specific IRM, and infection prevention in general.

7.4. LIMITATIONS

The results of this thesis should be interpreted in light of some limitations. First, while this thesis has focused specifically on behaviours relevant for the transmission of microorganisms, it should be recognised that transmission alone is not a necessary condition for patient infection and that other behaviours beyond those addressed in this thesis are highly relevant for infectious risk. These other behaviours include, for example, interventions that reduce patients' natural defences, such as the use of antimicrobials that alter the patients' natural flora and make him/her more susceptible to colonisation and infection from harmful microorganisms. Such behaviours, however, do not always occur at the bedside, making them difficult to observe. Other factors that increase a patient's risk of infection are inherent to the medical treatment they are receiving and thus cannot be avoided entirely, for example the risk of surgical site infection following non-elective surgery. Further, this thesis has specifically focused on behaviours related to contact transmission, and has not specifically addressed those related to airborne or droplet transmission of microorganisms.

Another limitation is related to the sample and setting. Much of the empirical work presented in this thesis is based on one university hospital set in a high-income setting. It is possible that risk behaviours and their determinants may vary in other settings. Although observations and interviews were done in a purposeful sample of various clinical settings, further research would be warranted to verify if these findings could be replicated in other organisational and national settings. The INFORM structured taxonomy has now been published and can be applied to assess the nature and frequency of IRM in further settings.

An important limitation of part 2 of this thesis relates to behavioural specification. Although efforts were made to define highly specific IRM and HSE behaviours during part 1, the behavioural analysis remained mostly broad and considered barriers and enablers to a wide range of IRM, rather than focusing on one or more specific IRM. This trade-off is recognized. For example, the behavioural analysis methods employed in this study did not explicitly consider the behavioural determinants of specific IRM, rather they identified factors that influence IRM behaviours in their totality. A more highly behavioural specific analysis may have led to more precise identification barriers and enablers. However narrowing the analysis too much could also make it difficult to generalise to other IRM and contexts. This is also a limitation to the systematic review, where identified barriers and enablers have so far been discussed in relation to compliance with infection prevention guidelines altogether, rather than breaking up the barriers and enablers per specific guideline and specific behaviour. Future research will build on the findings of this thesis, for example looking at how the identified barriers and enablers vary for different infection prevention behaviours and for specific IRM.

A final limitation relates to both studies where the TDF was explicitly used as a guiding framework, the video-reflexive ethnography and systematic literature review. In both of these studies, two criteria were used to assess the relative importance of domains. These included the frequency with which domains were cited and the elaboration of themes that emerged inductively within each domain. Although these criteria have previously been employed for both qualitative studies and secondary data analyses, they may be imperfect indicators of the domains that are actually the most relevant to the behaviours of interest. Findings from other domains that do not necessarily emerge as the most highly-relevant based on these criteria, should thus also be considered. A further technique that is also commonly employed in qualitative research methods is called member-checking (Patton, 2002). Member-checking involves feeding back a summary of study findings to participants and offering them the opportunity to confirm whether the findings accurately represent their reality, or if important findings have been overlooked.

7.5. Implications

The findings presented in this thesis have important implications for guiding both future research, and infection prevention practice. These implications, some of which have been alluded to throughout the thesis, are discussed in the following sections.

7.5.1. Implications for future research

Given the single-centre nature of this study, a natural next step for future research would be to use the INFORM observational taxonomy to identify local infectious risks and guide infection prevention efforts in additional settings. The INFORM taxonomy can be applied to identify local risks regardless of the guidelines in place or the extent of implementation of other infection prevention practices. As previously mentioned, the prioritisation of specific IRM has been proposed based on frequency of their occurrence together with expert consensus on likelihood of infectious outcomes. Rather than relying on expert consensus, microbiological studies to confirm that certain behaviours are specifically linked to transmission of microorganisms or infectious outcomes would further increase the strength of this approach and should thus be prioritised.

While considerable work has been done identifying the factors that are likely to influence individual health behaviours to prevent primary disease (e.g. smoking cessation, increasing physical activity), considerably less work has been done to comprehensively study the factors likely to influence HCP compliance with guidelines to prevent adverse patient events. With this in mind, this thesis has presented several qualitative studies designed to exploratively identify factors likely to influence behaviour. An important next step would be to undertake further studies to validate these factors and to assess their relative importance for influencing behaviour.

Finally, the last step proposed by the behavioural sciences paradigm for infection prevention (Figure 5), is to identify which interventions could address the barriers and strengthen the enablers identified through behavioural analysis. One method to approach this step is to map the identified barriers and enablers to corresponding intervention techniques, as proposed within the BCW approach (Michie et al., 2011). This will be discussed in more detail in the following section, Implications for Practice. Along the lines of mapping interventions to identified barriers and enablers, another interesting research agenda building on the work in this thesis is to assess the extent to which interventions within the field of infection prevention so far have employed intervention techniques that correspond theoretically with the barriers and enablers to infection prevention practice that have been identified. Such research is currently underway as a continuation of the current thesis. It involves first systematically identifying behaviour change interventions from the field of infection prevention. Next, the intervention approaches employed in identified studies are coded according to the *intervention functions* (Michie et al., 2011) or *behaviour change techniques* (Michie et al., 2008) that were employed. Finally, these interventions are mapped against identified barriers and enablers from TDF domains, to assess the theoretical coherence. A further step to give weight to this method, is to further assess intervention outcomes, and to evaluate whether interventions that employed intervention functions that were coherent with identified barriers and facilitators were more successful in achieving behaviour change than those interventions that did not. The quantitative results offered by such methods are critical for demonstrating to practitioners and policy makers of the importance of theoretically informed behaviour change interventions in healthcare overall, and infection prevention specifically.

7.5.2. Implications for practice

Given the applied nature of the research presented in this thesis, the implications for practice closely follow the implications for research. The most important implications for practice resulting from this thesis are those that concern the design of interventions to mitigate transmission of microorganisms that could cause patient harm. Firstly, this the studies presented in this thesis have demonstrated that a wide range of behaviours, including but also going beyond current indications for hand hygiene, are clinically relevant for the transmission of pathogens that involved in patient colonisation and infection. A majority of the behaviours examined in this thesis are not currently addressed by existing guidelines. Because each individual IRM appears to be of little risk, these behaviours have been largely unconsidered by infection prevention efforts. However, given the important cumulative risk represented by these frequently occurring behaviours, this thesis proposes that they should be given higher priority. Given the broad range of identified behaviours that are likely to be involved in the transmission of microorganisms to patients, a prioritisation is necessary. It would be neither desirable nor feasible to try to address all identified risk behaviours. The next step for practice would therefore be to prioritise IRM for intervention based on those that occur most frequently and are likely to have the highest clinical consequences. For example, based on the observations in this thesis, such behaviours included the inappropriate use of gloves – both wearing gloves for prolonged periods and potentially transmitting microorganisms from the environment to patient intact skin and critical sites, as well as donning gloves without hand hygiene and potentially contaminated gloves with foreign microorganisms prior to patient contact. Another highly relevant behaviour that emerged based on these observations was the frequent hand contact with surfaces throughout the patient environment, including those in the patient's direct environment likely to contain foreign microorganisms, prior to patient contact.

When considering interventions to address such behaviours, these must be designed to address the barriers and strengthen the enablers identified. As previously discussed, an advantage to the TDF framework is that it has been linked based on expert consensus to *intervention functions* that are theoretically coherent and therefore are likely to be effective in addressing the specific barriers and enablers within the TDF domains (Michie et al., 2011). A version of this mapping is shown in Table 25.

Given that environmental context and resources emerged as the most highly relevant TDF domain in two of the studies presented in this thesis, theoretically coherent intervention functions proposed by Michie et al. (2011) include (skills) training, restriction, environmental restructuring, and enablement. The fact that (knowledge) education does not figure among this list is a finding with major implications for infection prevention practice. This finding is of particular interest given than many traditional infection prevention efforts have focused on educational efforts to increase HCP knowledge and motivation, for example through guideline dissemination, resulting in only minor and often unsustained changes in HCP behaviour (Rubinson, Wu, Haponik, & Diette, 2005; Larson et al., 2007). The results of this thesis suggest that the limited efficacy of such interventions may be due to inadequate efforts to address the important physical barriers to HCP compliance.

Theoretical coherence, while an important criteria for designing interventions, must be taken into account along with other criteria to consider when designing interventions. Prioritisation of intervention approaches should also consider which interventions are most likely to be successful in changing behaviour, for example, based on a Hierarchy of Intervention Effectiveness (Cafazzo & St-Cyr, 2012). The Hierarchy of Intervention Effectiveness is a human-factors engineering and risk-management model that rates interventions in terms of how reliable they are likely to be. This hierarchy places technological and structural interventions, which would correspond with the intervention function *environmental restructuring*) high on the hierarchy of effectiveness, while interventions such as education and training related are esteemed to be less reliable. This is not to say that education and training are not without value, rather that structural and technological interventions that shape behaviour may be more effective in preventing error than those that require conscious reflection and rely on having adequate cognitive resources to prevent error.

Table 25: Mapping TDF domains to intervention functions

TDF Domain	Intervention functions
1. Knowledge	Education
2. Skills	Training
3. Social/Professional Role and Identity	Education Persuasion Modelling
4. Beliefs about Capability	Education Persuasion Modelling Enablement
5. Optimism	Education Persuasion Modelling Enablement
6. Beliefs about Consequences	Education Persuasion Modelling
7. Reinforcement	Training Incentivisation Coercion Environmental restructuring
8. Intentions	Education Persuasion Incentivisation Coercion Modelling
9. Goals	Education Persuasion Incentivisation Coercion Modelling Enablement
10. Memory, Attention and Decision Processes	Training Environmental restructuring Enablement
11. Environmental Context and Resources	Training Restriction Environmental restructuring Enablement
12. Social influences	Restriction Environmental restructuring Modelling Enablement
13. Emotion	Persuasion Incentivisation Coercion Modelling Enablement
14. Behavioural Regulation	Education Training Modelling Enablement

7.6. CONCLUSIONS

This thesis has presented and applied a behavioural science paradigm to guide infection prevention efforts. This paradigm informed the Infectious Risk Moment approach, which sought, in two parts, to first systematically identify and quantify HCP behaviours that are relevant for transmission of microorganisms that can result in patient colonisation and infection, and second to understand the full range of barriers and enablers (i.e. behavioural determinants) that influence these behaviours.

The main findings from the eight studies included in this thesis allow for the following overarching conclusions:

1) Healthcare provider behaviours related to the transmission of microorganisms include, yet go beyond exiting indications for hand hygiene. While hands and gloves continue to be among the most important contributors to transfer of microorganisms, further relevant infectious risk behaviours also involve vectors such as medical devices, mobile objects, invasive devices, and HCW clothing and accessories. While any of these behaviours alone is associated with only medium-to-low likelihood of infectious outcome[iii], their cumulative frequency (with IRM occurring on average once every 1.4 minutes of active care and colonising HSE occurring once every 1.01 minutes) makes them highly clinically relevant.

2) The factors that influence healthcare provider behaviours relevant to infectious risks are many, including physical, social, and cognitive processes. Based on both empirical studies and theoretically informed data synthesis, the most relevant barriers to safe HCP behaviour were related to lack of sufficient resources (e.g. time, space, materials, adequate guidelines) and difficult physical and organisational context (e.g. urgency, competing salient events). Other important influences on HCP behaviour

[iii] Based on expert consensus

were social, including influences from colleagues (e.g. social norms, social pressure, role modelling) and from patients, where HCP concerns about patient perceptions influenced HCP infection prevention behaviours. Finally, cognitive processes and HCP knowledge (e.g. procedural knowledge, awareness of guidelines, knowledge about microbiology and transmission dynamics) were found to enable safe infection prevention behaviours when sufficient, but also to be an important barrier when missing.

Together, these findings have important implications for guiding future infection preventions, beginning by informing the design of theoretically informed behaviour change strategies to address these identified risks. The findings and approach presented in this thesis should further serve the community of infection prevention and control researchers and practitioners as a guide for prioritising future research, training, and quality improvement initiatives.

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EDUCATION

2015/03 – present	Doctoral Programme, Applied Social and Health Psychology Supervisors: Prof Urte Scholz, Prof Hugo Sax Institute of Psychology, University of Zurich, Switzerland Thesis title: "Development and application of a behavioural science paradigm for infection prevention"
2012/09 – 2014/12	MSc in Applied Ergonomics (Human Factors Engineering) Supervisor: Dr Sue Cobb University of Nottingham, United Kingdom Thesis title: "Role of visual cues for isolation precaution compliance"
2007/08 – 2011/05	BA in Biology, French, and International Studies (Triple Major) Supervisor: Prof Greg Murray Hope College, Holland, MI, United States of America

EMPLOYMENT HISTORY

2012/05 – present	Infection prevention project leader HumanLabZ Behavioural Sciences Lab Coordinator (www.humanlabz.org) Infection Control Program, Zurich University Hospital – Zürich, Switzerland Supervisor: Prof Hugo Sax
2013/09 – 2014/03	Research Assistant Industrial Psychology Department, University of Fribourg – Fribourg, Switzerland Supervisor: Prof Tanja Manser
2012/02 – 2012/05	Patient Safety Intern Clean Care is Safer Care, First Global Patient Safety Challenge, WHO World Health Organization, Patient Safety Program – Geneva, Switzerland Supervisor: Dr Benedetta Allegranzi
2011/05 – 2012/05	Research Assistant Infection Control Service, University Hospitals of Geneva – Geneva, Switzerland Supervisors: Prof Didier Pittet, Dr Walter Zingg

Approved research projects

- Virtual reality enhanced behaviour-change training for healthcare-associated infection prevention (VIRTUE), funded by The University Hospital Zurich Foundation, Awarded to Hugo Sax, Lauren Clack, Marcel Wenger, Andreas Kunz, 2018, 340'000 CHF
- Systematic literature review on the behavioural determinants of infection prevention guideline compliance, Funded by Swiss Federal Office of Public Health, Awarded to Lauren Clack and Hugo Sax, 2016, 56'100 CHF
- Implementation of a Surgical Unit-Based Safety Program in African Hospitals: A qualitative inquiry, Funded by the World Health Organisation, Awarded to Lauren Clack and Hugo Sax, 2015, 17'850 USD
- HFE-Informed design of signage for isolation precautions, Funded by the Quality Management and Patient Safety Department of the University Hospital Zurich, Awarded to Lauren Clack and Hugo Sax, 2013, 20'000 CHF

Selected Awards

- Best presentation of innovation in infection control, Swiss Society for Hospital Hygiene Annual Congress, "Design and validation of visual cues to improve isolation compliance," 2015, Interlaken CH (2nd Place, 300 CHF)
- University Hospital of Zurich Q-Award 2015 co-recipient for the project, "Neuen Hygienekonzept USZ - eindeutig, benutzerfreundlich, zugänglich" (*New USZ hygiene concept – clear, user-friendly, and accessible*)
- Best presentation of innovation in infection control, Swiss Society for Hospital Hygiene Annual Congress, "Infectious Risk Moments – A novel, human factors-informed approach to infection prevention." 2014, Aarau CH (3rd Place, 100 CHF)

Peer-reviewed Publications

- Clack L, Passerini S, Manser T, Sax H. Likelihood of infectious outcomes following Infectious Risk Moments during patient care - an international expert consensus study and quantitative risk index. *Infection Control and Hospital Epidemiology* 2018 Mar;39(3):280-289. doi: 10.1017/ice.2017.327.
- Clack L, Passerini S, Wolfensberger A, Sax H, Manser T. Frequency and nature of Infectious Risk Moments during acute care based on the INFORM Structured Classification Taxonomy. *Infection Control and Hospital Epidemiology 2018 Mar;39(3):272-279. doi: 10.1017/ice.2017.326.*
- Clack L*, Scotoni M*, Wolfensberger A, Sax H. "First-person view" of pathogen transmission and hand hygiene - use of a new head-mounted video capture and coding tool. *Antimicrobial Resistance & Infection Control* 2017. 108(6)
- Van der Kooi T, Sax H, Pittet D, van Dissel J, van Benthem B, Walder B, Cartier V, Clack L, et al., on behalf of the PROHIBIT consortium. Prevention of hospital infections by intervention and training (PROHIBIT): results of a pan-European cluster-randomized multicenter study to reduce central venous catheter-related bloodstream infections. *Intensive Care Medicine* 2017 https://doi.org/10.1007/s00134-017-5007-6
- Zingg W, Holmes A, Dettenkofer M, Goetting T, Secci F, Clack L, Allegranzi B, Magiorakos A, Pittet D. Hospital organization, management, and structure in the context of healthcare-associated infection prevention: a systematic review. *The Lancet Infectious Diseases* 2015. 15(2) 212-224

- Clack L, Schmutz J, Manser T, Sax HS. Infectious Risk Moments: a novel, Human Factors-informed approach to infection prevention. *Infection Control and Hospital Epidemiology* 2014. 35(8) 1051-1055
- Clack L, Kuster S, Giger H, Guiliani F, and Sax H. Low-hanging fruit for human factors design in infection prevention – still too high to reach? *American Journal of Infection Control* 2014. 42(6) 679-681
- Sax HS, Clack L, Touveneau S, Da Liberdade F, Pittet D, Zingg W, on behalf of the PROHIBIT study group. Implementation of infection control best practice in intensive care units throughout Europe: a mixed-method evaluation study. *Implementation Science* 2013. 24(8) 1-11

BOOK CONTRIBUTIONS

- Clack, LC and Sax HS. Ch. 27: Human Factors Design and Hand Hygiene, in *Hand Hygiene: A Handbook for Medical Professionals.* Wiley-Blackwell Health Sciences. 2017.

ADDITIONAL SCHOLARLY WRITING

- Kuster S, Wolfensberger A, Schreiber P, Clack L, Sax H. Infektionsprävention ist «Change Management». *Swiss Medical Forum* 2018. 18(1-2):13-15
- Sax H, Wolfensberger A, Clack L, Meier MT. Handlungsweisendes Informationssystem für Infektionsprävention – ein Ansatz in Human Factors Engineering. Informationsschrift Koordinierter Sanitätsdienst 1/17.
- Clack L and Sax H. Human Factors Engineering and Inpatient Care–New Ways to Solve Old Problems. *Annals for Hospitalists 2017.* 166(8) H02-H03.
- Sax H and Clack L. Mental models – a basic concept for human factors design in infection prevention. *Journal of Hospital Infection* 2015. 89(4) 335-339
- Sax HS, Stewardson A, Allegranzi B, Boyce JM, Clack L, Larson EL, Pittet D. Commentary on Chou DTS, et al. The World Health Organization '5 Moments of Hand Hygiene. *J Bon Joint Surg Br* 2012;94-B:441-5.

ORAL CONTRIBUTIONS TO CONFERENCES

- Clack L, Bogdanovic J, Passerini S, Manser T, and Sax H. Video reflexive ethnography: uncovering healthcare provider risk perceptions. BSAS Meeting 2017 (Invited talk)

  Clack L. Video-reflexive Ethnography: Ein praktisches Instrument für Ihre Infektionsprävention-Toolbox. Zürcher Hygienekreis, Zurich CH, September 2017 (Invited talk)
- Clack L. Qualitative Research Methods: Practical applications for Infection Prevention. Swiss Society for Hospital Hygiene Annual Congress, Basel CH, August 2017 (Invited talk)
- Clack LC and Sax H. (Webber Talk) Results of qualitative research on implementation of infection control best practice in European hospitals. Webber Training, July 2016 (Invited talk)
- Clack LC, Willi U, and Sax H. Lessons learned from SUSP program implementation in Africa: A qualitative study. WHO guidelines for the prevention of surgical site infections: implementation strategy and tools meeting, Geneva CH, June 2016 (Invited talk)
- Clack LC, Meier M, Stühlinger M, Venema S, Sax H. Design and validation of visual cues to improve isolation compliance. Swiss Society for Hospital Hygiene Annual Congress, Interlaken CH, September 2015 (Oral presentation, recipient of 2nd place prize for best innovation)

- Clack L, Meier M, Stühlinger M, Venema S, Sax H. Visual cues to improve healthcare worker compliance with isolation precautions. Applied Human Factors and Ergonomics, Las Vegas, USA, July 2015 (Oral presentation)
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